USER CONSIDERATIONS

ABOUT INPUT

INPUT provides planning information, analysis, and recommendations to managers and executives in the information processing industries. Through market research, technology forecasting, and competitive analysis, INPUT supports client management in making informed decisions. Continuing services are provided to users and vendors of computers, communications, and office products and services.

The company carries out continuous and in-depth research. Working closely with clients on important issues, INPUT's staff members analyze and interpret the research data, then develop recommendations and innovative ideas to meet clients' needs. Clients receive reports, presentations, access to data on which analyses are based, and continuous consulting.

Many of INPUT's professional staff members have nearly 20 years' experience in their areas of specialization. Most have held senior management positions in operations, marketing, or planning. This expertise enables INPUT to supply practical solutions to complex business problems.

Formed in 1974, INPUT has become a leading international consulting firm. Clients include over 100 of the world's largest and most technically advanced companies.

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INPUT Planning Services for Management

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IMPROVING THE PRODUCTIVITY OF ENGINEERING AND MANUFACTURING USING CAD/CAM USER CONSIDERATIONS

A MULTICLIENT STUDY

DECEMBER 1981

INPUT

2471 E. BAYSHORE ROAD, SUITE 600, P.O. BOX 50630, PALO ALTO, CA 94303 (415) 493-1600

February 12, 1982

Dear Client:

The enclosed report, Improving the Productivity of Engineering and Manufacturing Using CAD/CAM, User Considerations, is part of INPUT's CAD/CAM multiclient study.

Previously released volumes of this study analyzed specific applications of CAD/CAM systems. This volume takes a broader approach and addresses issues facing users in general; it also compares user responses to selected issues. The intent of this volume is to both complement and supplement the analyses and discussions of the application volumes.

User experiences and needs on selected issues are discussed, followed by more general management-oriented topics including products and services, future directions, government and university programs, and management considerations.

We welcome your comments and questions.

Sincerely,

Bud Kocher

C. E. "Bud" Kocher
Manager, CAD/CAM Multiclient Study

CEK:ml

Enclosure

IMPROVING THE PRODUCTIVITY OF ENGINEERING AND MANUFACTURING USING CAD/CAM USER CONSIDERATIONS

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IMPROVING THE PRODUCTIVITY OF
ENGINEERING AND MANUFACTURING
USING CAD/CAM
USER CONSIDERATIONS

EXHIBITS

I INTRODUCTION

I INTRODUCTION

A. PURPOSE AND SCOPE

- This volume, produced by INPUT as part of a five-volume CAD/CAM (computer-aided design/computer-aided manufacturing) multiclient study analyzes user needs and experiences with CAD/CAM systems and services.

- The primary purpose for the INPUT CAD/CAM study was to provide a research-based report on this dynamic and rapidly growing industry.

  - A wide variety of reports and reference materials are available on CAD/CAM, but they are from numerous sources and typically deal with either a narrow range of issues or are of the "catalog" variety with little or no analysis.

- This study was designed to gain first-hand responses to key issues confronting users and vendors. In this regard, the INPUT study is the first to be based on a large sample of direct interviews dealing with CAD/CAM.

- The study is worldwide in scope with interviews conducted in:

  - United States.

  - Western Europe.

  - Japan.

- Due to the size and maturity of the domestic CAD/CAM industry, over 80% of the user interviews were conducted in the U.S. Nondomestic interviews were conducted to allow an assessment of the similarities or differences with U.S. findings.

- Five subject areas were examined:

  - Worldwide markets for products and services.

  - General user issues and considerations.

  - Mechanical engineering applications.

  - Electronic engineering applications.

  - Architectural engineering applications.

- In-depth interviews conducted with both users and vendors covered the following five topics:

  - Technology.

  - Productivity improvements.

  - Software.

  - CAD/CAM integration.

  - Maintenance and support.

- The main emphasis of the study is on user experiences, perceptions, and needs.

- There are many opinions on the status, direction, and needs of the CAD/CAM industry.

- Leading vendors are proceeding along their own paths which are not always in concert with the user community.

- In fact, the market is shaped and driven by the users of CAD/CAM systems. They may be influenced by forces outside their community, but their needs constitute the main driving force.

B. METHODOLOGY

1. USER SURVEY

- The primary source of information for this project was an extensive set of user interviews conducted with managers or senior technical people who were directly involved with CAD/CAM system operations.

- Respondent companies were randomly selected from a variety of sources including INPUT internal lists, referrals, and vendor supplied lists.

- INPUT conducted 201 user interviews, as shown in Exhibit I-1. A list of respondent titles and company names is shown in Appendix C.

- Approximately 40% of the user interviews were conducted on-site by senior consultants; the remainder were conducted by telephone.

- Every attempt was made to balance the interviews across the using company size spectrum so that a true cross-section of responses would be obtained, as shown in Exhibit I-2.

EXHIBIT I-1

DEMOGRAPHIC PROFILE OF USER RESPONDENTS

TYPE \ LOCATION	UNITED STATES	JAPAN	EUROPE	TOTAL
Mechanical	61	6	19	86
Electronics	59	6	6	71
Architectrual/ Engineering	39	3	2	44
Total	159	15	27	201

EXHIBIT I-2

SIZE PROFILE OF USER RESPONDENTS
(TOTAL COMPANY SALES)

COMPANY SIZE / TYPE	SMALL < $0.1 billion	MEDIUM $0.1-1 billion	LARGE >$1.0 billion
Mechanical	21%	21%	44%
Electronics	12%	12%	47%
Architectural/ Engineering	3%	4%	37%

NOTE: Architectural/Engineering size profile: small, <$2 million; medium, $2 - 10 million; large, >$10 million

- It was not possible within the scope of this study to obtain a balanced distribution of architectural users.

- Small firms (under $2 million in annual sales) do not represent a significant segment of the CAD/CAM user population.

- A general questionnaire was developed to explore issues common to all three application areas. Issues unique to each application were then added to the general questionnaire.

- A copy of the questionnaire for each application area may be found in the appendices of the respective applications volumes.

- The questionnaires were coded and entered into a data base for analysis.

2. VENDOR SURVEY

- Interviews were conducted with 40 vendors (80% on-site). Vendor respondent titles and company names are shown in Appendix C.

- Vendor questionnaires addressed the same issues as the user questionnaires, as well as market-related factors.

- As with the users, vendor respondents were selected to obtain a balance of company size and application concentration.

- The vendor questionnaires were not analyzed statistically due to several factors:

    - Direct comparison of responses was not valid because of the wide variety of company sizes, applications concentration, and product delivery mode (turnkey, software, hardware, or remote computing services).

- Some vendor responses were incomplete for reasons of confidentiality.

- A copy of the vendor questionnaire may be found in the appendices of the respective applications volumes.

3. ADDITIONAL SOURCES

- Supplemental sources of information for the research and analysis phases consisted of:

  - Technical papers and journals.

  - Conference proceedings.

  - Trade publications.

  - Newsletters.

  - Vendor literature and documentation.

- Additional insight was provided by members of the academic community and external consultants.

4. QUALIFICATION OF RESULTS

- The range of issues and the depth to which they were to be explored, compounded by the large number of interviews and the international aspects, resulted in a massive and very complex project.

- Some limitations were imposed on the final report structure and scope over what was presented in the study proposal, but these changes should not affect the value of the report to the subscribers.

- The questionnaires were designed by INPUT senior staff members with assistance from charter study sponsors and outside consultants. The questions selected represent a compromise forced by the scope of the project and the interests of the charter group.

- The rates of response vary across most of the questions due to a number of factors:

  - Terminology - every attempt was made to use standardized terms, but terminology varies widely even within the same application area.

  - Turnover - in some cases it was difficult to find respondents who had been with their company long enough to be familiar with all aspects of the system, especially the "historical" questions dealing with system justification and selection.

  - Sophistication - a range of user sophistication was encountered from those who perceived their system as merely an "electronic T square" to highly sophisticated users pushing the technology to its limits.

  - Perspective - perspectives ranged from very narrow (concerned only with using the system to perform a specific set of tasks) to very broad (able to see the CAD/CAM capability as it related to their total operation); as such, some users were unable to adequately respond to certain issues.

  - Measurement - some quantitative data were not available because either the installation was too new to have accumulated data experience or the system manager simply was not collecting it.

- Most data fields have sufficient sample sizes to be statistically significant; where this is not the case, the results should be treated as indicators only and inferences drawn with caution.

- Many data exhibits found in these reports use the terms "average" and "mean"; both are used to indicate the arithmetic mean of sample data.

C. PREFACE

- The INPUT CAD/CAM multiclient report is divided into five separate volumes:
  - User Considerations.
  - Market Analysis and Forecasts.
  - Mechanical Engineering Applications.
  - Electronic Engineering Applications.
  - Architectural Engineering Applications.
- This volume is concerned with the issues facing users in general and avoids application-specific discussions where possible. Some overlap exists among the volumes, but it is minimal.
- Application-specific issues are discussed in their respective volumes.
- Data are displayed and their implications discussed for most data fields common to all applications questionnaires.
- The intent of this volume is to:
  - Identify and discuss common issues facing users.
  - Report and analyze their perceptions and reactions.

- Review external forces and predict their impact.

- Offer recommendations formulated as a result of numerous user interactions.

• INPUT could not address all issues of concern to the user community, but feels confident that the presentation of the combined experiences of the respondents will be of value to clients in their complex and demanding involvement with CAD/CAM.

II EXECUTIVE SUMMARY

II EXECUTIVE SUMMARY

A. BACKGROUND

- This computer-aided design (CAD) and computer-aided manufacturing (CAM) study conducted by INPUT focuses primarily on interactive graphics-based systems. Computers have been used for design and manufacturing tasks for over 25 years, but interactive graphics systems have resulted in dramatic gains in productivity since the first turnkey systems were released in 1970.

- The CAD/CAM industry is undergoing rapid and dramatic changes due to technological advances and widening user understanding and acceptance. Systems which only the largest corporations could afford are now within the reach of smaller companies.

- The scope and depth of the contribution of CAD/CAM systems to the total design and manufacturing process is beginning to be realized as utilization expands beyond the more simple mechanical functions (such as drafting and layout) to new applications.

- This study was conducted to gain a more in-depth understanding of this complex and rapidly growing field.

  - It was sponsored by both users and vendors.

- Interviews were conducted in the U.S., Western Europe, and Japan with 204 users and 40 vendors. Eighty percent of the users' and 65% of the vendors' interviews were conducted in the U.S.

- The main emphasis of the study was to explore users' experiences, perceptions, and needs.

B. KEY OBSERVATIONS

- CAD systems have become a critical factor in the product development process of many companies:

  - A number of electronics companies stated they could not develop products without CAD systems, because of product complexity and the requirement of shortened design time.

  - Mechanical applications users cite the benefits of a shortened design cycle, greater skilled manpower productivity, increased accuracy, and the more rapid availability of design data to downstream processes.

- Large companies are clearly the leaders in effective use of CAD/CAM due to their more extensive experience with the technology. Most small companies interviewed by INPUT had not progressed beyond automating the more simple functions of drafting and basic design. Both large and small companies, however, are experiencing attractive productivity gains and other economic benefits and find CAD/CAM systems to be an excellent investment.

- The rapid rate of change in the CAD/CAM industry is making new demands on managers and their organizations. Managers must keep up with the new technologies and changes within their organization such as new methods and procedures, redeployment of people, and new skills requirements as well as changes in organizational roles and interrelationships.

- CAD/CAM systems produce a dramatic shortening of time scales in areas such as design and analysis, drafting and layout, modifications or changes, and information transfer between functions. This requires a high degree of flexibility and adaptability at all levels of a company if the full benefits of CAD/CAM are to be realized.

- CAD/CAM will grow in importance as more company functions are automated and integrated into a total system. During the 1980s systems will be capable of capturing product data at its source, through the design process; then automatically disseminating it to all other functions and processes without the need for manual intervention or transformation. While this integration has not progressed very far, it is one of the highest priority issues for both users and vendors.

C. USER EXPERIENCES

- Users generally expressed satisfaction with their CAD/CAM systems. The overall average response of 6.2 (on a scale of 1 equals not important, 10 equals vital) indicates that their systems more than meet the expectations they had at the time of purchase.

- Even though many users complained about vendor service and a feeling of being "locked-in" (due to the incompatability between vendors), most reported that they would buy from the same vendor if they were to start over again.

	Would Buy From Same Vendor
Mechanical users	94%
Electronics users	82%
Architectural users	83%

- Reported productivity gains varied widely (from 0% to over 4,000%) depending on the uses of the systems, the applications areas, and the age of the installation. Typical responses were in the 100% to 300% range.

  - Some users reported little or no directly measurable productivity gain, but were satisfied with their system because it met other needs such as accuracy, quality, or standardization.

  - Productivity measurement appeared to be a very weak area in a number of respondent firms. This represents an area for improvement since this information is important for performance measurement and new system justifications.

- The average total cost for CAD/CAM workstation use by respondents was reported to be \$40 per hour, growing to \$55 in 1986 (including labor, overhead and system costs). The most significant cost increase will be in labor.

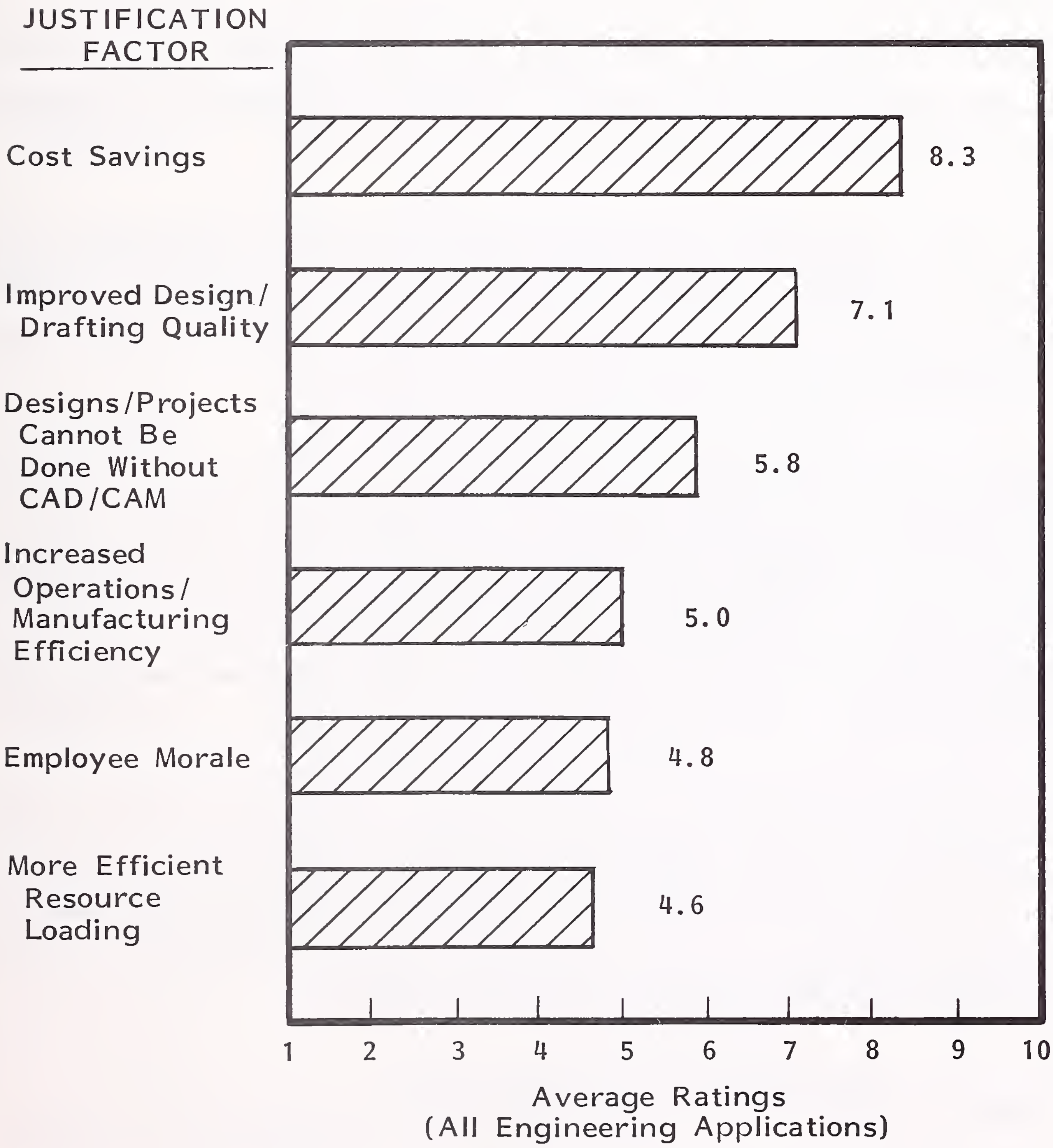
- Sixty percent of all respondents reported using specialist workstation operators as opposed to infrequent or casual operators. This is due to the present complexity of workstation operations, the extensive training required, and equipment expense. Lower cost (per function) and more user-friendly systems will allow the use of more casual operators, leading to wider use and better controlled costs.

- Many systems appear to have been justified on a very cursory analysis; most systems are justified for easily measurable applications, such as simple design or drafting, and initial productivity gains can be quite high.

- The importance users place on various system justification factors is shown in Exhibit II-1. Users should expect a shift in priorities over time resulting in justification factors which change in importance. Subsequent justifications will become more difficult to analyze as new systems are required for more complex, less easily measured tasks. Discussions of justification factors and recommendations may be found in Chapters III and IV.

EXHIBIT II-1

RESPONDENTS' RATINGS - IMPORTANCE OF SYSTEM JUSTIFICATION FACTORS



SCALE: 1 = Not Important, 10 = Vital

- Another area requiring improvement was in the system selection process. Some companies reported system selection based on an evaluation of only one or two systems, even though monetary and other commitments were significant.

- Exhibit II-2 shows the importance respondents placed on various system selection factors. The most concern was shown for software and processing capabilities plus the demand for the system to be flexible to meet future requirements. Cost was considered the least important (assuming that all vendors were reasonably close in cost).

- Individual companies will most likely have other factors which they also consider important to add to the list. A number of recommended factors and issues are discussed in Chapter VII.

- One factor which INPUT recommends be given thorough consideration is the prospective vendor's maintenance and software support capabilities, because of the importance of a reliable, highly available CAD/CAM system to any company's operation.

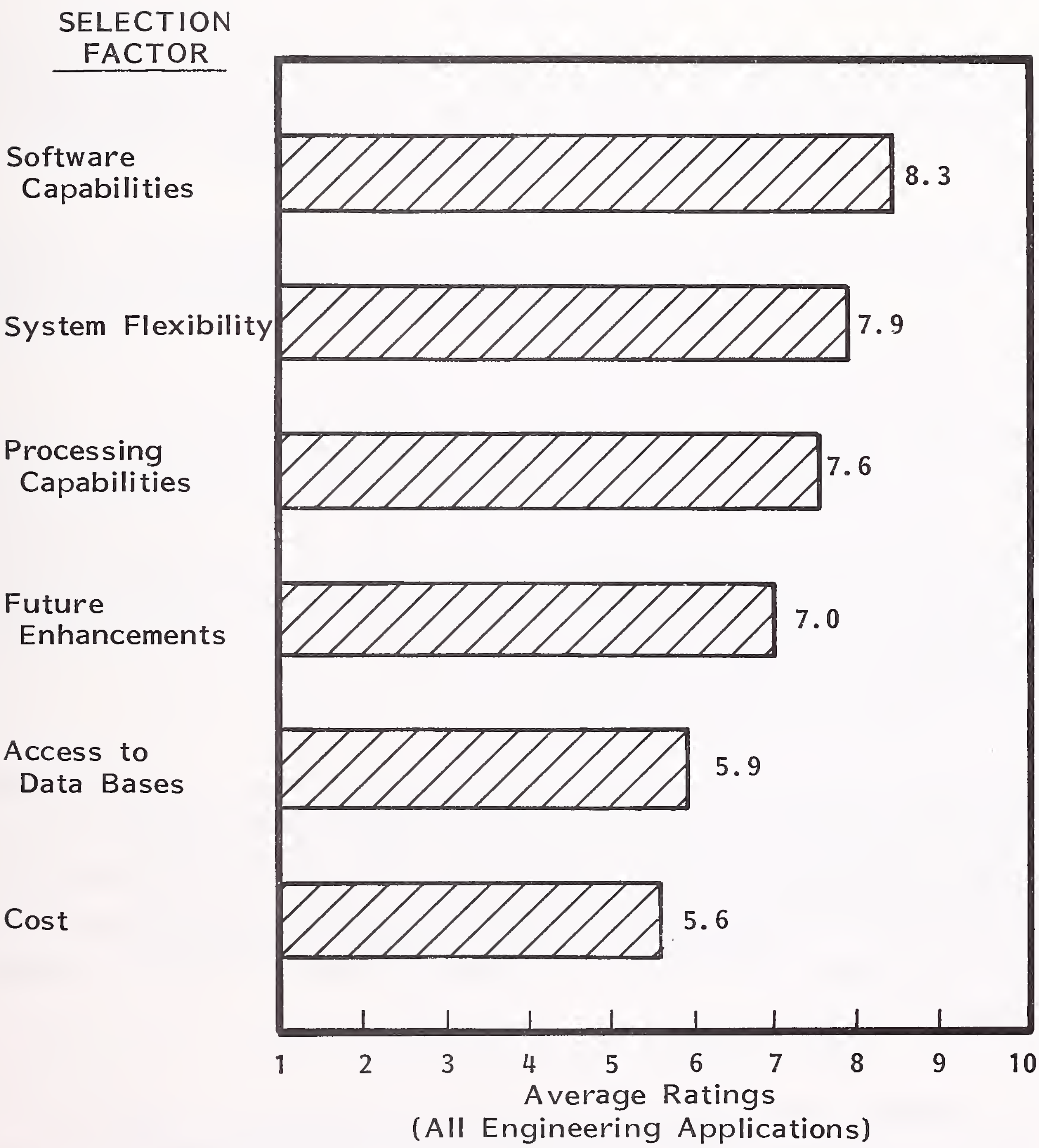
- Rapidly evolving technology in microelectronics is creating dramatic advances in CAD/CAM systems performance and architecture. Declining costs for semiconductor memories and microprocessors are allowing vendors to distribute storage and processing functions to peripherals (such as workstation displays) and special purpose processors to reduce the load on the central system processor.

- This increased intelligence (or functionality), resulting in greater system capacity, will encourage wider systems usage in terms of additional applications. As the number of applications grows and it becomes more feasible to distribute workstations and limited function systems, the need to tie these components together becomes a critical issue.

- Integration exists today to a very limited degree:

EXHIBIT II-2

RESPONDENTS' RATINGS -
SYSTEM SELECTION FACTORS



SCALE: 1 = No Impact, 10 = Major Impact

- A number of large corporations have major projects underway to integrate their engineering, manufacturing, and management information systems. These efforts are highly customized and proprietary, so little of their efforts will reach the marketplace.

- Turnkey system vendors are offering a wider variety of applications, but most are vertically integrated (that is, they operate only on the turnkey system) or have very limited interfaces to external systems and applications.

- User respondents rated the status of integration at 3.6 in 1981 and projected it to be at 6.5 in 1986 (on a scale of 1 equals unimportant, 10 equals vital). A sampling of vendor responses showed very similar responses.

- Users generally agreed that two major obstacles to integrating CAD and CAM were lack of standards and incompatible systems components. Another highly rated factor was organizational conflict.

- Lack of standards and incompatible components are closely related. Device interconnection standards are well defined, but the more critical area of data interchange is not. Users expressed concern that data standards would take five years or more to be developed. Their immediate concern was being able to interconnect different turnkey systems to allow design and other data to be freely moved from system to system.

- Government and industry efforts are being directed toward the development of a graphics data exchange standard and substantial progress should be made toward acceptance in the next several years. A number of U.S. vendors have already announced acceptance of the Initial Graphics Exchange Specification (IGES) which forms the basis for the proposed American National Standards Institute standard.

- Data exchange standards are certainly one critical area if integration is to progress, but another is the development of data base management systems

(DBMS). A DBMS allows a user to define data structures and relationships and provides him with accessing and control capabilities.

- Data base systems are necessary to establish efficient access to data distributed across various systems within a corporation. Vendors are aware of this need and most listed DBMS as the major new software development in 1986. The data management problem will also be attacked in the mid-1980s by specialized "back-end" data base processors.

- The CAD/CAM systems of the mid-1980s will offer users considerably more flexibility and freedom of choice than they have today.

  - The trend toward decentralized, remote workstations with more intelligence and functional capacity will continue.

  - Networking capabilities will allow users to establish integrated systems consisting of intelligent workstations, full function standalone workstations, multiple station systems, and mainframes.

  - Processor technology will continue to improve, resulting in distributed, special purpose processors for graphics functions, communications, and data management tasks. This will further increase the capacity of the system processor for computations and additional stations.

  - Display technology has advanced rapidly. High resolution raster scan display was rated by users as the best for their needs in 1986. Users will have a very wide choice of display capabilities (resolution, color, local dynamic functions, size) in several years.

- The major challenges confronting users in the 1980s will be:

  - Keeping abreast of the CAD/CAM industry.

  - Making the proper choices from a wide range of offerings.

- Integrating products into an effective system.

- Maintaining a flexible and responsive organizational environment.

III USER EXPERIENCES AND NEEDS

III USER EXPERIENCES AND NEEDS

A. INTRODUCTION

- The growth and viability of the CAD/CAM industry depend to a great extent on high technology.

- Powerful, and more importantly, affordable systems are available today because of the rapid advances in processor, storage system, and display technology.

- However, technology only allows an industry to develop; it is the user community which drives an industry.

- INPUT focused on the user environment as the most critical force shaping and driving the CAD/CAM market.

- User responses showed wide variances as expected, but there was a clear consensus on most issues; sometimes it was expressed on an individual applications basis and at other times it was industry wide.

- The pattern of user responses can provide valuable information for both vendors and users; vendors to set or check strategies and users as a basis for comparison or a source of new ideas.

B. SYSTEM SELECTION AND USE

- Given the magnitude of the commitment involved in implementing a CAD/CAM system, some of the findings of selection and use were very surprising.

- Selection methods ranged from almost casual purchase to rigorous evaluation and exhaustive testing.

  - Many users were unaware of the capabilities of systems other than the one they purchased.

  - Small companies tended to be less rigorous in their evaluations, even though the economic consequences were proportionately higher.

- While no detailed functional utilization statistics were compiled, it was apparent that many users have not progressed beyond using their system for drafting or the most basic design activities. Small companies appear to be the most prevalent under-utilizers of system capabilities.

- Many of the topics explored in this section merit further investigation and will be considered for future INPUT research projects.

1. SYSTEM JUSTIFICATION

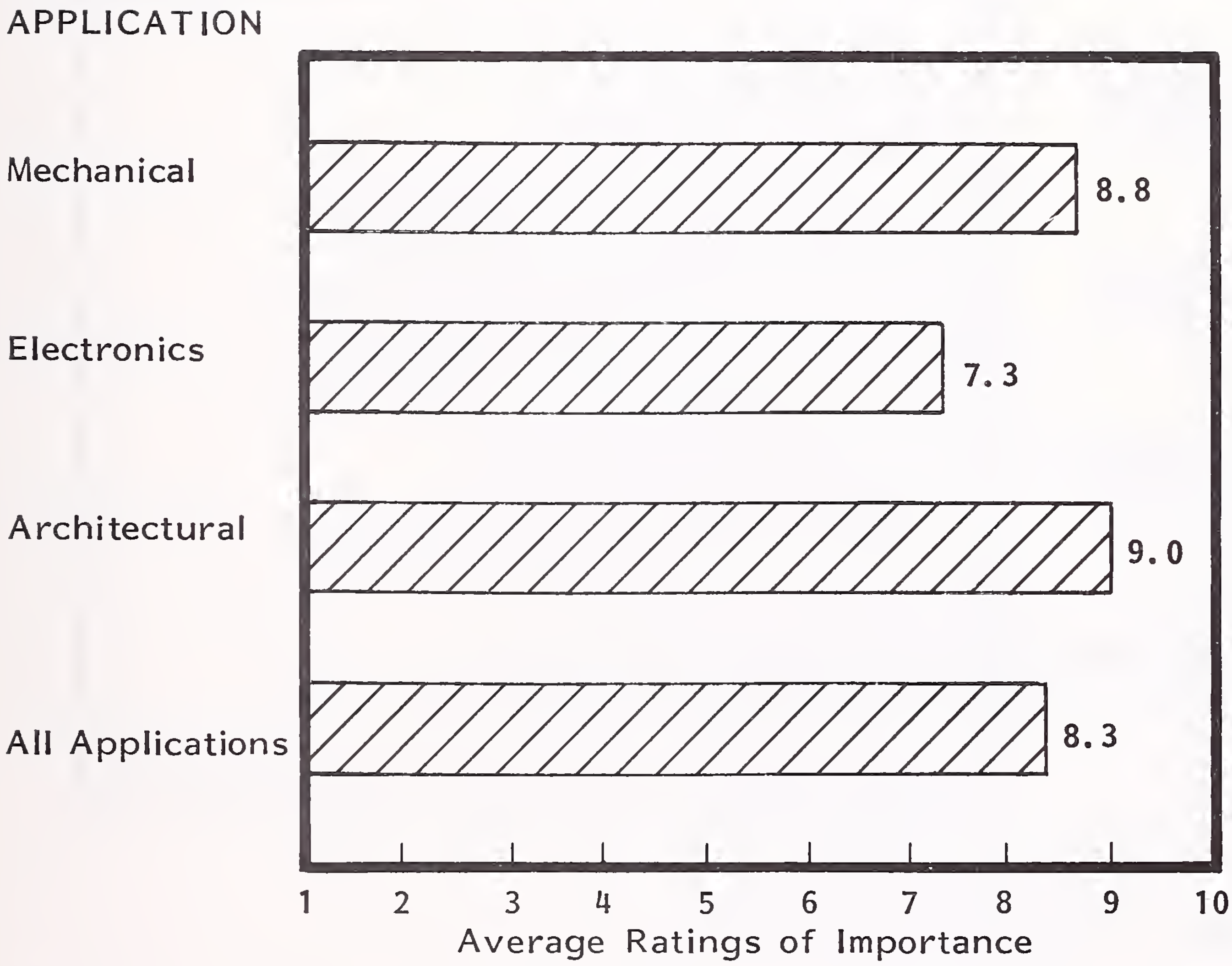
- INPUT polled users on the importance they placed on a number of system justification factors, as shown in Exhibits III-1 through III-6.

- One aspect of system justification that could not be investigated within the scope of this program was how these factors were applied.

  - Employee morale, for example, may have been given a high rating, but it was treated as a side issue compared to cost savings in the formal justification.

EXHIBIT III-1

SYSTEM JUSTIFICATION FACTORS - COST SAVINGS



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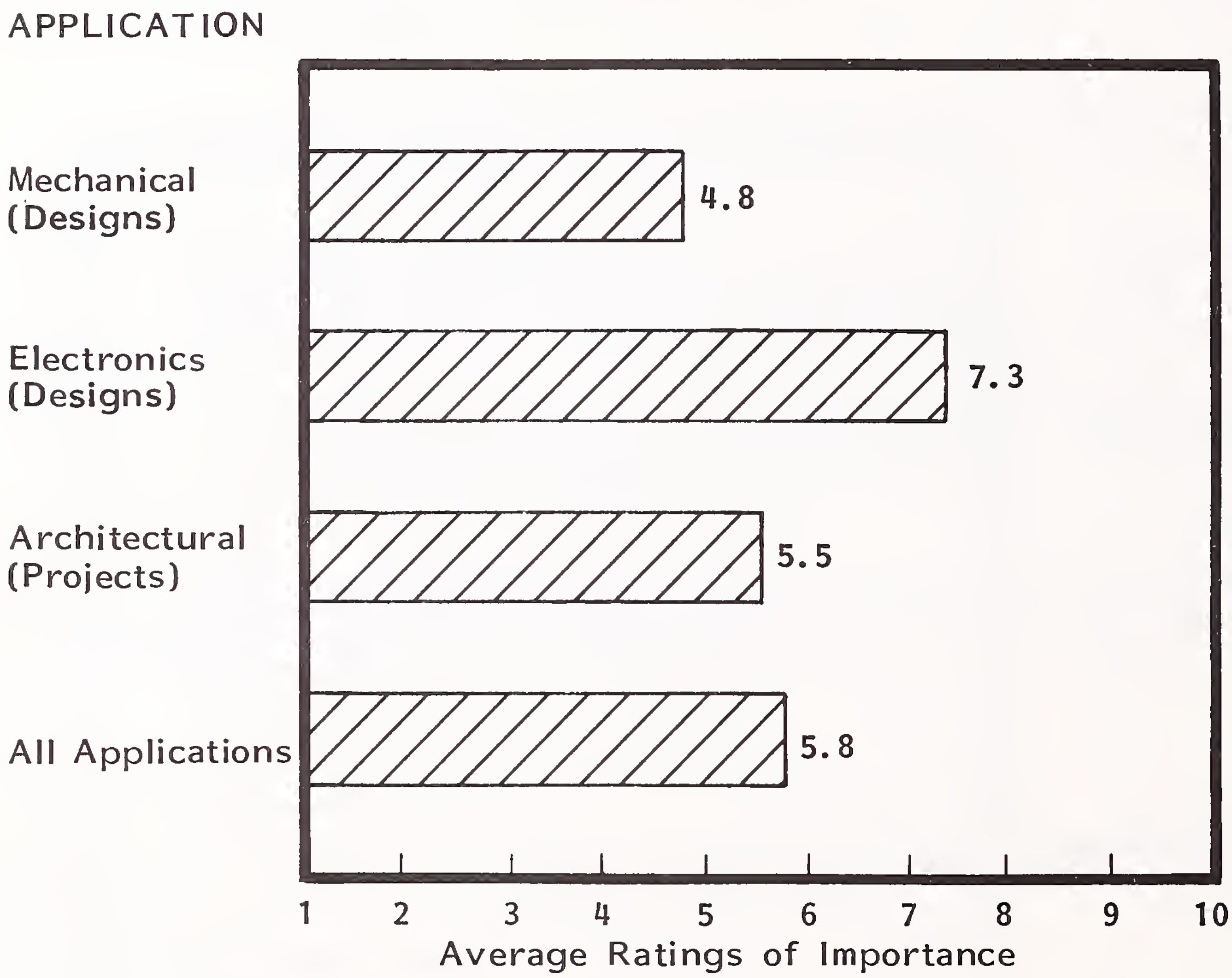
*DETAIL APPENDIX A

EXHIBIT III-2

SYSTEM JUSTIFICATION FACTORS - DESIGNS/PROJECTS CANNOT BE DONE WITHOUT CAD/CAM



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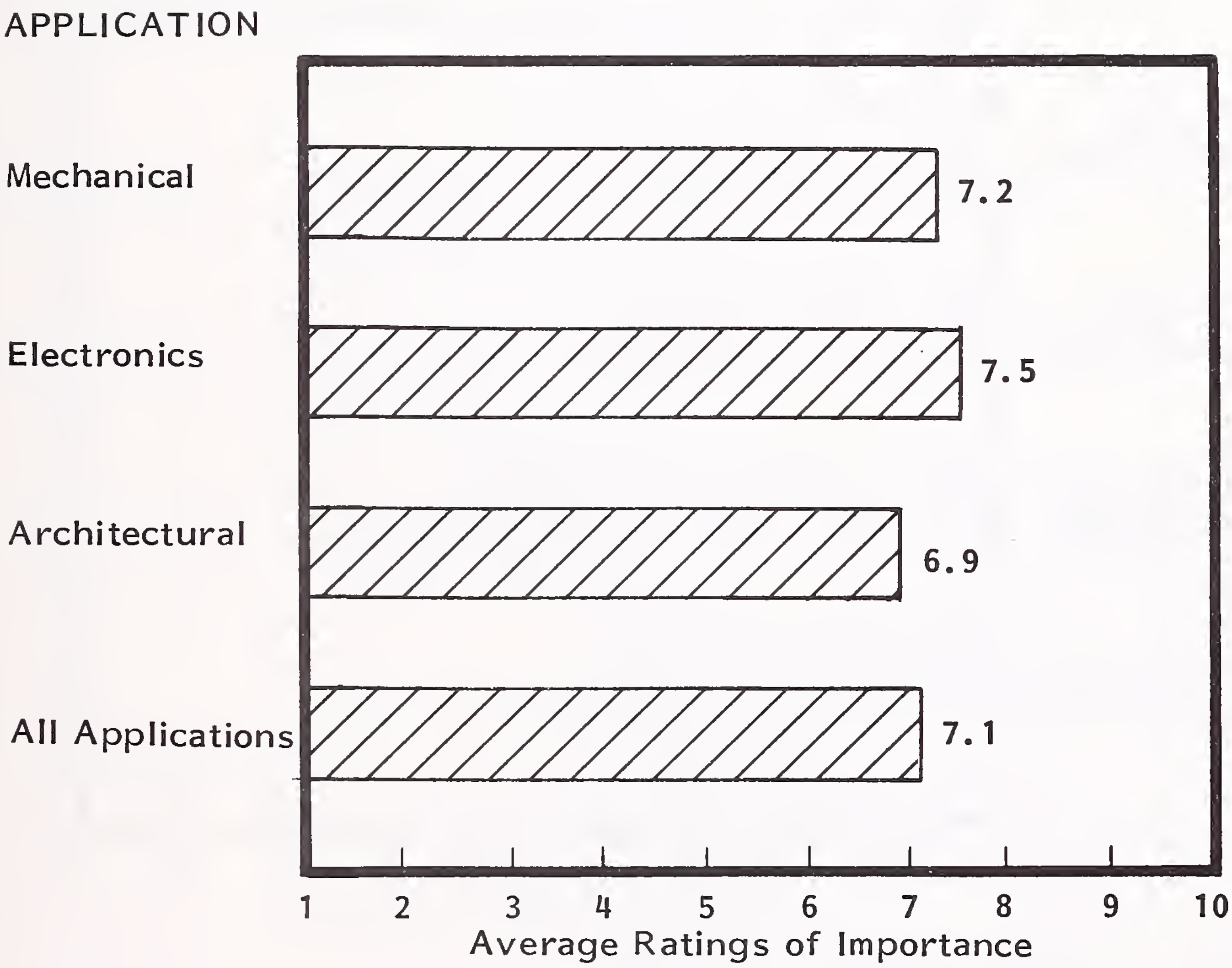
*DETAIL APPENDIX A

EXHIBIT III-3

SYSTEM JUSTIFICATION FACTORS-
IMPROVED DESIGN/DRAFTING QUALITY



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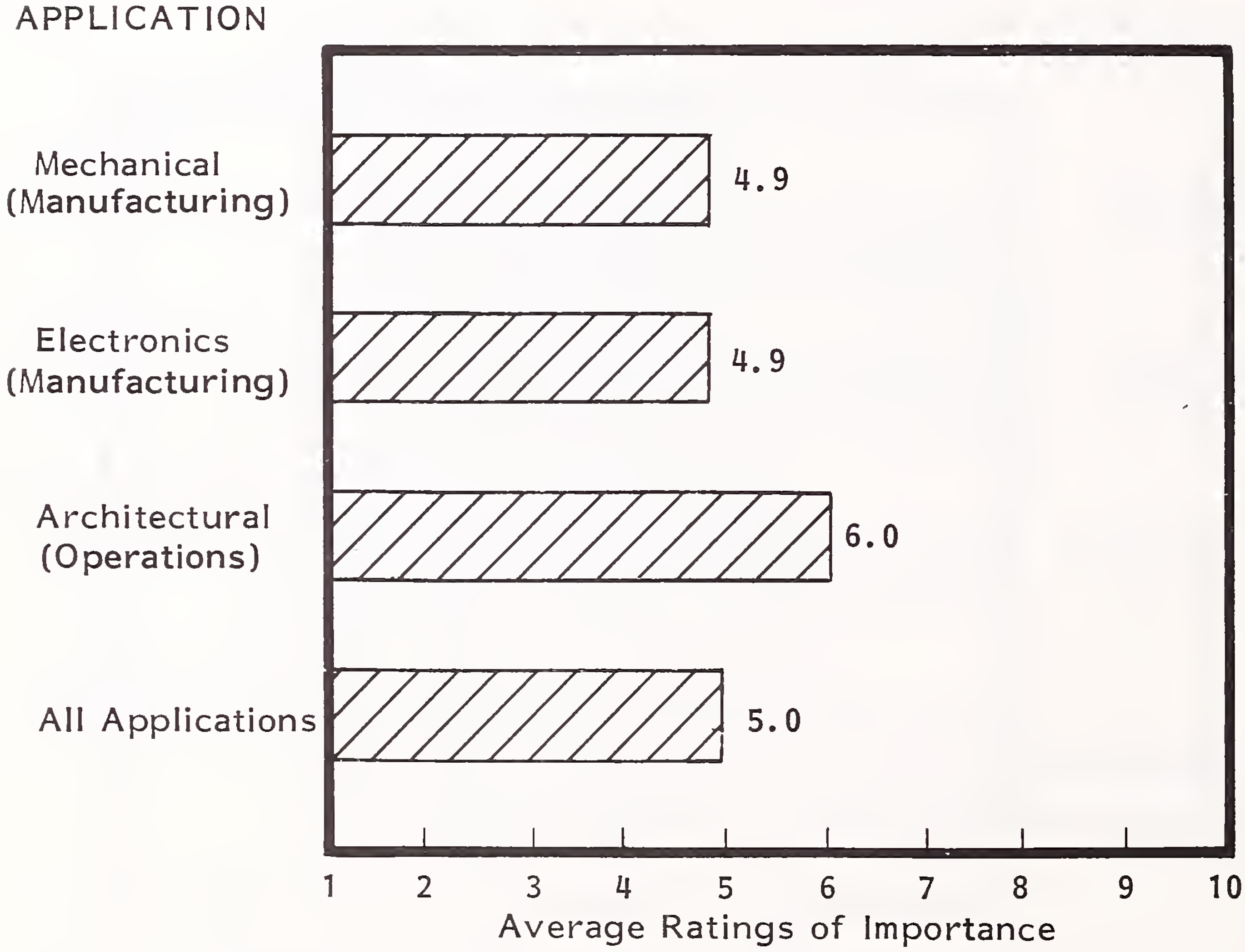
*DETAIL APPENDIX A

EXHIBIT III-4

SYSTEM JUSTIFICATION FACTORS-
INCREASED OPERATIONS/MANUFACTURING EFFICIENCY



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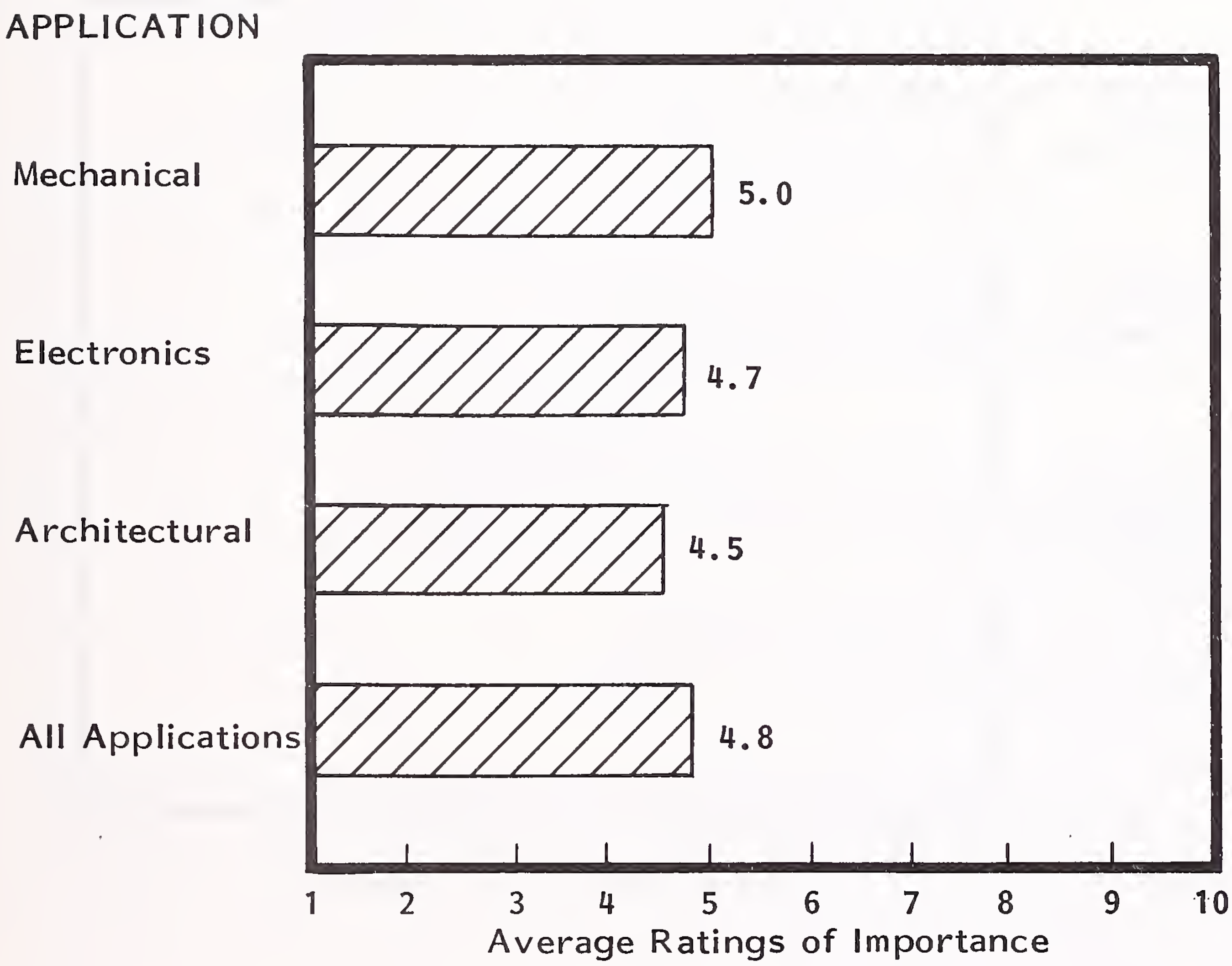
*DETAIL APPENDIX A

EXHIBIT III-5

SYSTEM JUSTIFICATION FACTORS-
EMPLOYEE MORALE



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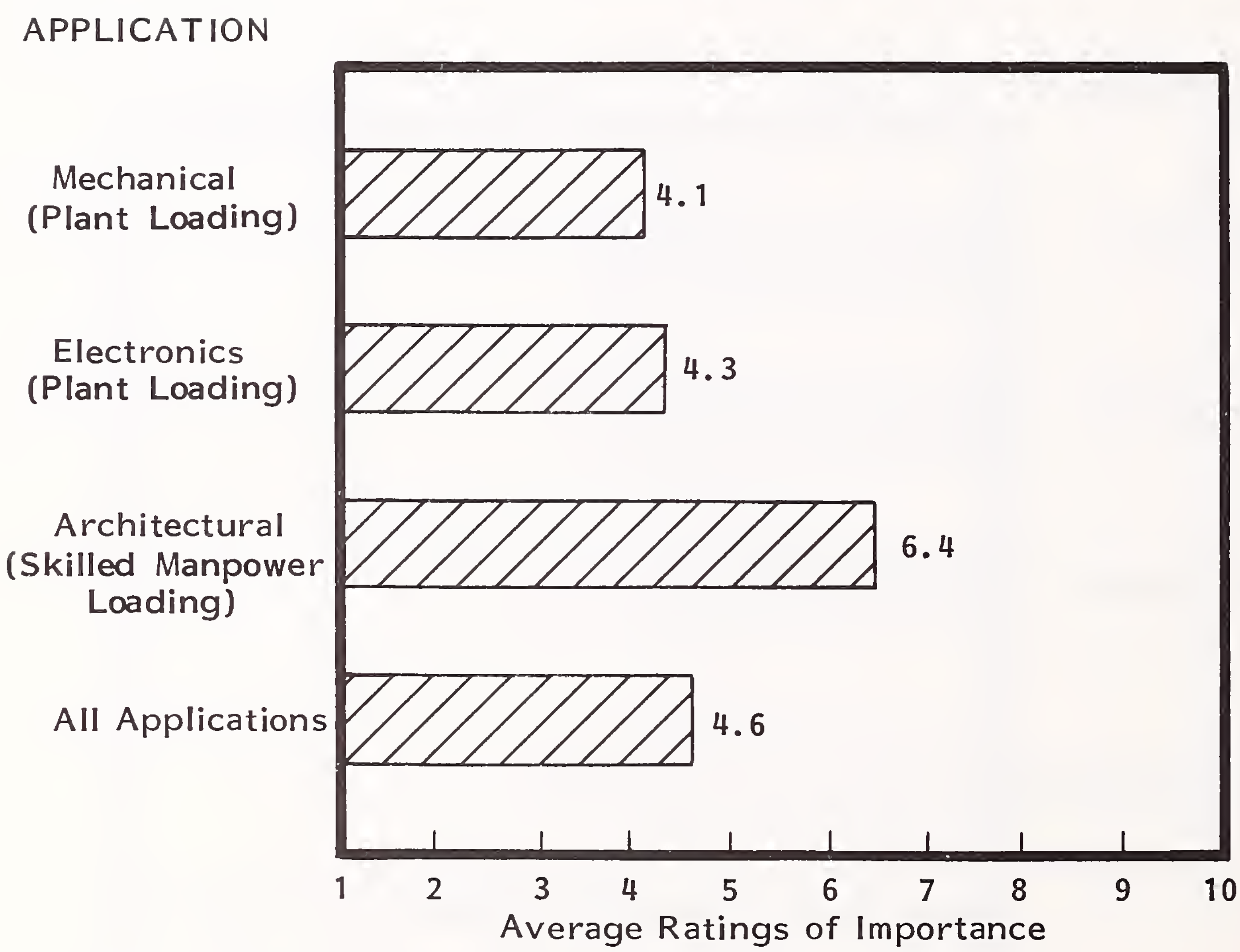
*DETAIL APPENDIX A

EXHIBIT III-6

SYSTEM JUSTIFICATION FACTORS-
MORE EFFICIENT RESOURCE LOADING



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*DETAIL APPENDIX A

- One user summarized the use of justification criteria very well, "All of the factors are important, but I can't put a dollar figure on them that everyone will believe, so I have to fall back on direct cost savings."

- Cost savings (often cost-avoidance of additional staffing) are definitely important, but the value being realized from other factors must be determined such as:

  - The value to the corporation of improved design and drafting quality, of the capability to acquire new projects, or of more efficient skilled manpower loading.

  - The effect on morale when engineers are trained (and effectively skill-improved) on a CAD/CAM system.

  - The savings realized by a shortening of the total product cycle.

- Initial systems are usually the easiest to justify because they attack the most obvious and easily measured problems.

  - Raising new issues for the justification of incremental systems can cause credibility problems if they are not well founded and thoroughly documented.

- While most of the criteria used in the questionnaire can be translated into cost savings, Exhibit III-1 refers to cost savings in their most basic and obvious context - directly measurable savings such as fewer draftsmen (or higher productivity) due to less time to produce a drawing.

  - Not surprisingly, users gave this factor the highest ratings.

- Electronics applications users gave the cost savings issue less weight than other applications because some electronics companies can no longer develop their products without CAD.

- Product complexity has risen dramatically.

- Competitive pressures have shortened the design-to-market time.

- Over 60% of the electronics users rated cost savings at eight or less, compared to less than 35% for mechanical and architectural users.

  - It is worth noting that 20% of electronics users rated cost a five or below.

- "Designs/projects cannot be done without CAD/CAM," was clearly an important factor for electronics, as expressed in Exhibit III-2, owing to the complexity of integrated circuit designs.

  - Generally, mechanical engineering users did not consider this to be a significant factor; exceptions were some aerospace firms and specialized job shops because of complex designs and subcontractors, due to contractor preferences or requirements for the use of CAD.

- CAD/CAM systems will be a requirement in the future as they become more widely used.

  - Some government and private contracts give preference to contractors who use them.

  - Improved design accuracy is one consideration, but the more important consideration is data exchange. The exchange of design data, standards, and documentation, is much more efficient via computer media (although standards represent a problem today).

- "Design and drafting quality" was highly rated by all users and is one of the most visible and important benefits of CAD/CAM, as noted in Exhibit III-3.

- Quality remains high in both design and drafting because the user is relieved of repetitive, tedious, and time consuming tasks.

- Users reported more thorough design analyses because of the ease of performing them on the system and because the faster design time produced fewer schedule problems and hence less shortcutting.

• Putting a dollar figure on improvement in quality can be extremely difficult because it is hard to quantify.

- Managers should be alert to cases where it can be proven and measured, so that criteria can be developed and documented for use in future add-on or new system justifications.

• The justification factor "increased operations/manufacturing efficiency" drew mixed responses from the respondents, as shown in Exhibit III-4.

- Integration of overall operations or reliance on the system for critical projects were usually the determinants for a high rating.

• As CAD/CAM systems penetrate deeper into company functions through integration with other applications, this factor will grow in importance.

- Systems will be critical links in total operations because of their capability for capturing product data at its point of creation and disseminating it quickly and accurately.

- Users must find a means of determining the value of a system to overall operations to justify future upgrades.

• The average rating for "employee morale" in Exhibit III-5 was about midscale for all three engineering applications, yet many users expressed concern over personnel issues.

- "Employee morale" may have been too narrowly stated to elicit a valid response to the broader personnel issue.

- The rapid growth of CAD/CAM is placing severe demands on most users to find, train, and retain "system-intelligent" engineers.

- Some users reported that having a system was a definite aid in attracting and retaining skilled engineers.

- There were a few reports of a system having a negative effect on morale:

  - Employees feared replacement or layoffs due to increased efficiencies.

  - Many people (especially older ones) resisted learning new methods; an attitude characterized by one manager as a "T-square mentality."

- The potential for adverse reactions to the new system can easily be overlooked by a manager. If they arise, he could be confronted with them at the worst possible time - when he is trying to get the system established.

- Negative reactions from outside the user organization have also been reported as a response to precious budget dollars being spent for "engineering's expensive new toy."

- "More efficient resource loading," rated by respondents in Exhibit III-6, was posed as "plant loading" to mechanical and electronics users and "skilled manpower loading" to architectural.

- Responses to this factor typically measured the degree of integration of CAD/CAM with plant operations.

  - The electronics industry has a longer and more intensive history in the use of CAD/CAM and hence slightly more integration.

- The scattering of high mechanical responses represents a wide variety of companies and products, pointing out the early stage of integration in this market segment.

2. SYSTEM SELECTION FACTORS

- Selecting a CAD/CAM system is a very crucial decision:

  - Start-up costs and operations disruptions can be significant during the first year of operation.

  - The on-going commitment involves new costs, but more importantly, potentially major operational changes.

  - The monetary and operational impacts can be severe if a bad decision is made and a system must be replaced (not to mention career impacts on the managers responsible for evaluation and selection).

- System selection techniques or procedures were not explored directly in the INPUT research, but the extent of the process was fairly clear from responses to other issues (such as comparative rankings of vendor capabilities).

- A significant number of users performed cursory, if any, evaluation of more than one other vendor's system.

  - The prevailing attitude seemed to be that all of the systems were "about the same," so there was no significant risk in their decision.

  - This may be valid for users who only see their systems being used for a single, basic function such as drafting, but it can be risky if additional applications are planned for the future.

- The initial selection decision carries a consequence that is often overlooked: the difficulty of installing additional systems from other than the original vendor.

  - This can be far-reaching because of differences in operation, coordination of support, difficulties in interconnecting or integrating different systems, and limited flexibility in transferring people and projects from system to system.

- Small and medium size companies typically do not have the resources to perform extensive comparisons and analyses.

  - They rely heavily on vendor-provided information, which is not the most objective source.

  - They consider a number of factors, but often the deciding one is cost.

  - They rely heavily on recommendations from other users.

- Cost was not rated as highly by the respondents as other selection factors, as shown in Exhibits III-7 through III-12.

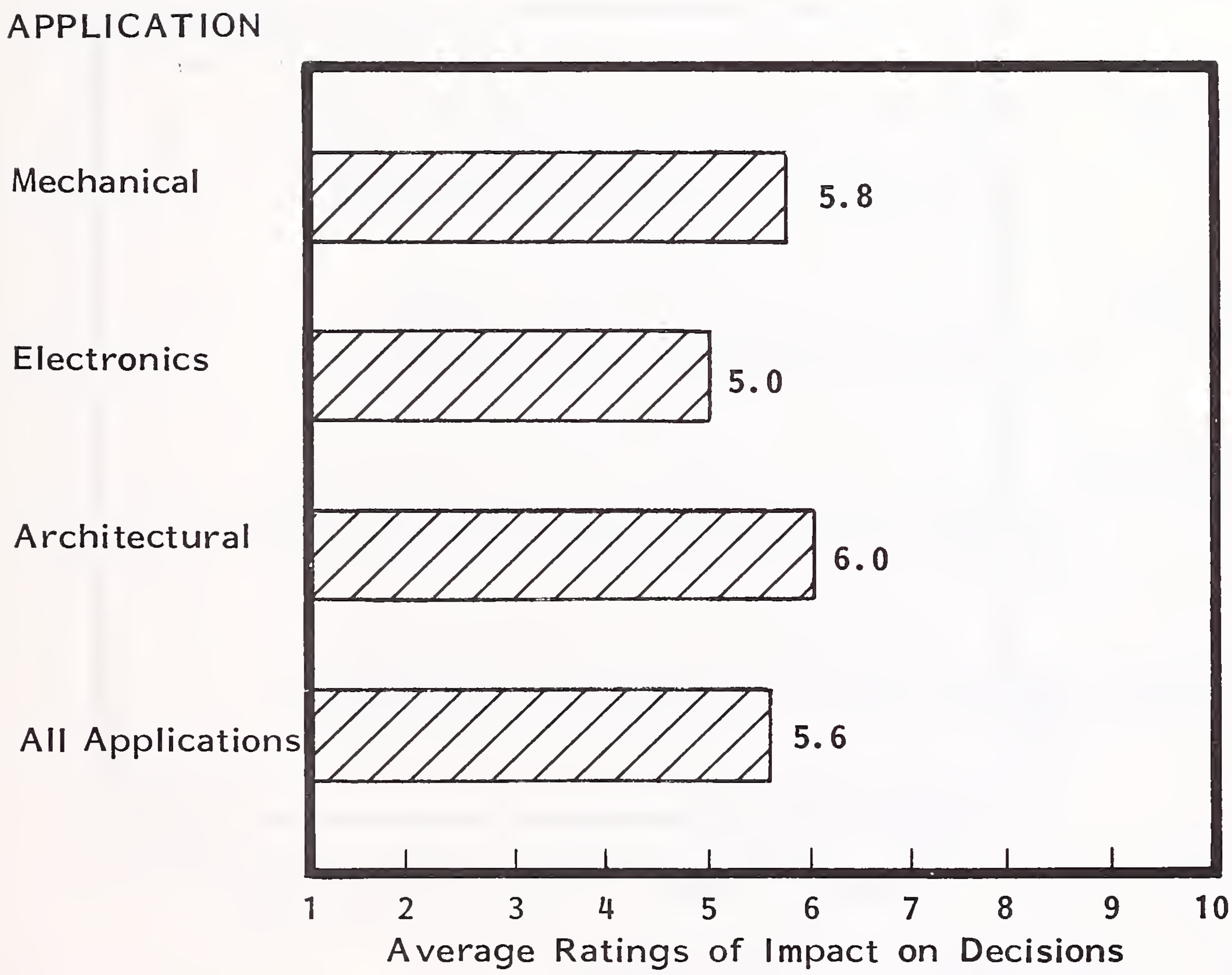
- Cost typically was an important consideration for small companies, although several very large companies also rated it highly.

  - The rationale for some users was that they considered prospective vendors closely equivalent in other selection factors (as far as their needs were concerned), so selection came down to a matter of price.

- Processing capabilities were rated surprisingly high for all three applications, as shown in Exhibit III-8.

EXHIBIT III-7

SYSTEM SELECTION FACTORS - COST

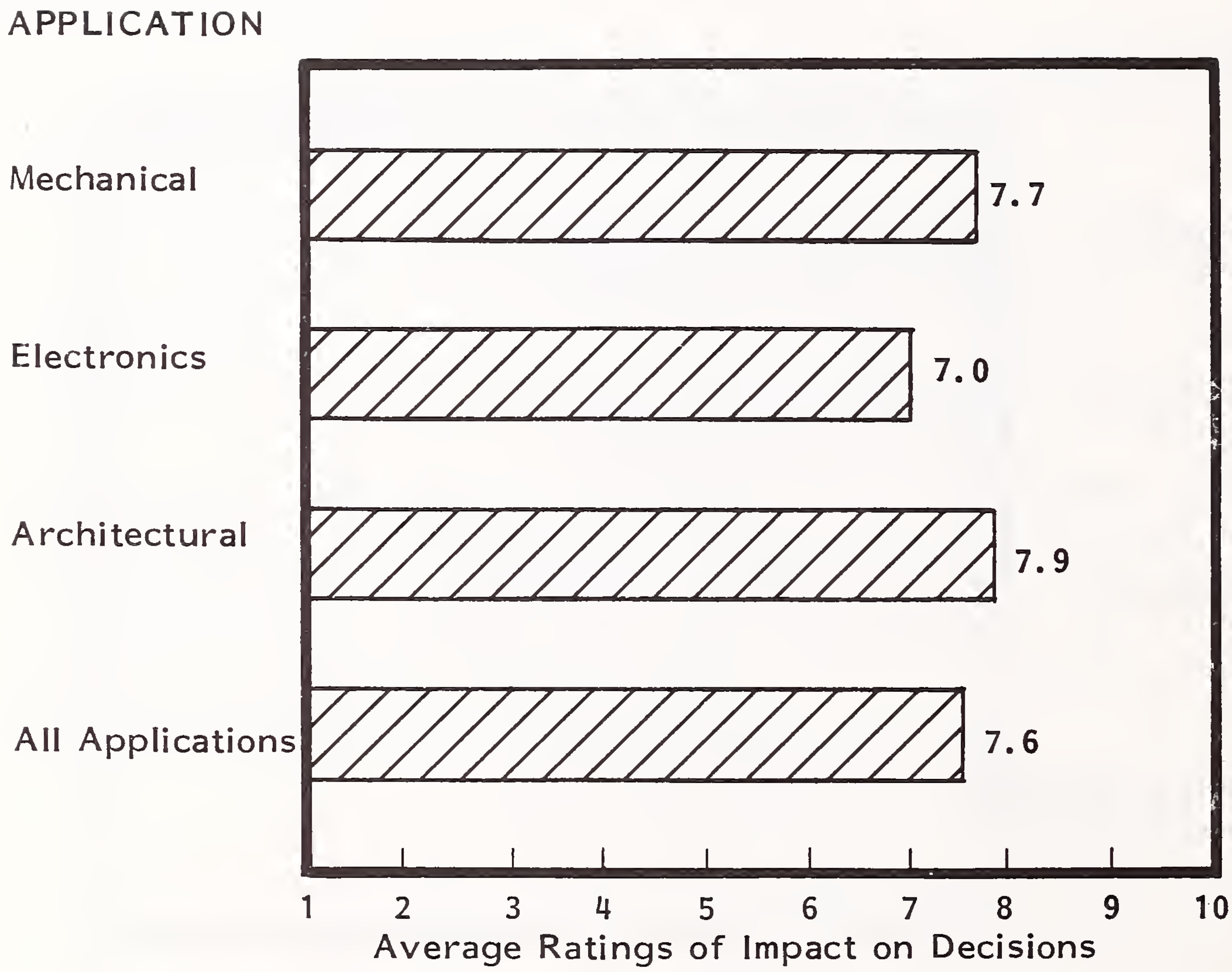


Scale: 1 = No Impact, 10 = Major Impact

*DETAIL APPENDIX A

EXHIBIT III-8

SYSTEM SELECTION FACTORS-
PROCESSING CAPABILITIES

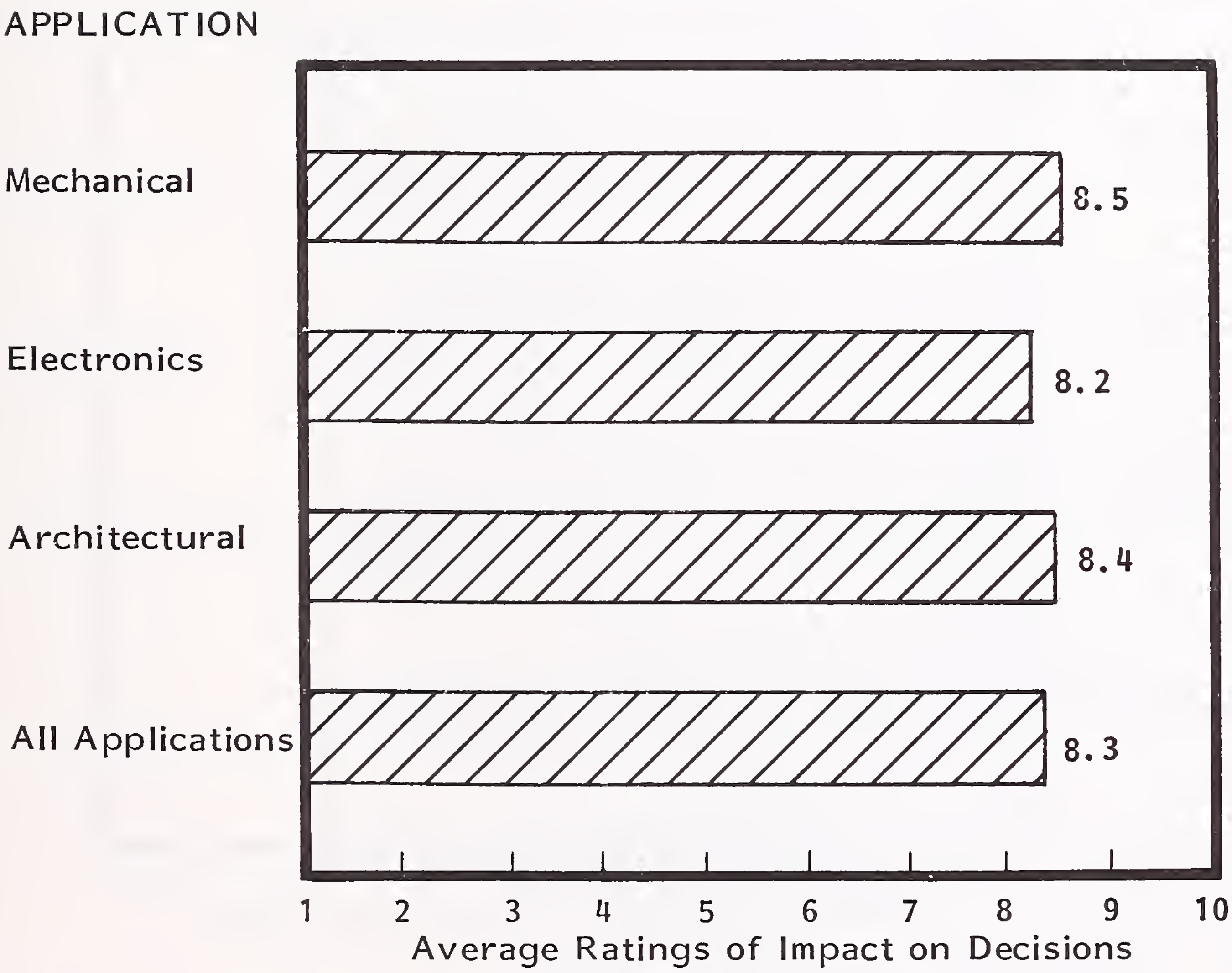


Scale: 1 = No Impact, 10 = Major Impact

*DETAIL APPENDIX A

EXHIBIT III-9

SYSTEM SELECTION FACTORS-
SOFTWARE CAPABILITIES

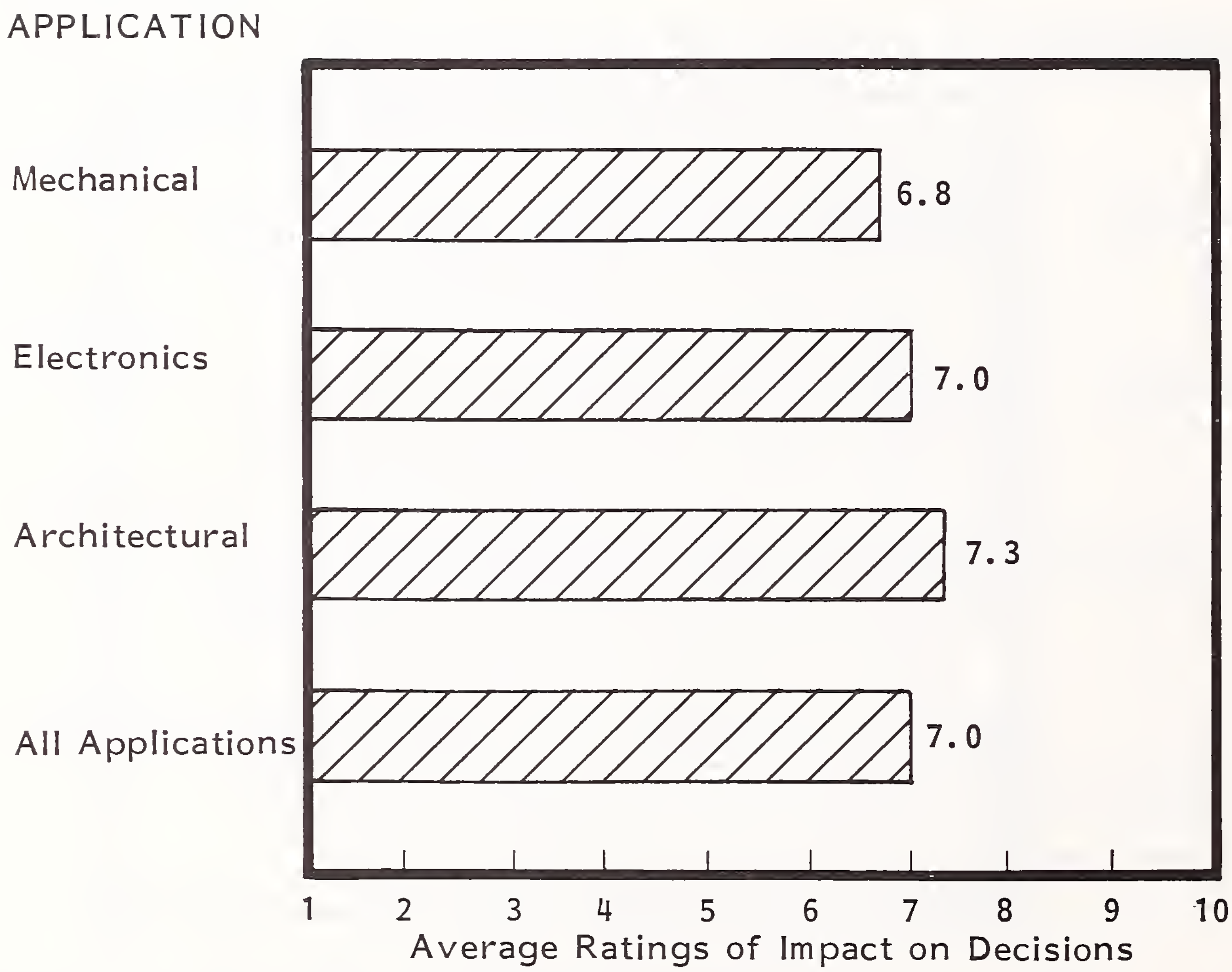


Scale: 1 = No Impact, 10 = Major Impact

*DETAIL APPENDIX A

EXHIBIT III-10

SYSTEM SELECTION FACTORS-
FUTURE ENHANCEMENTS

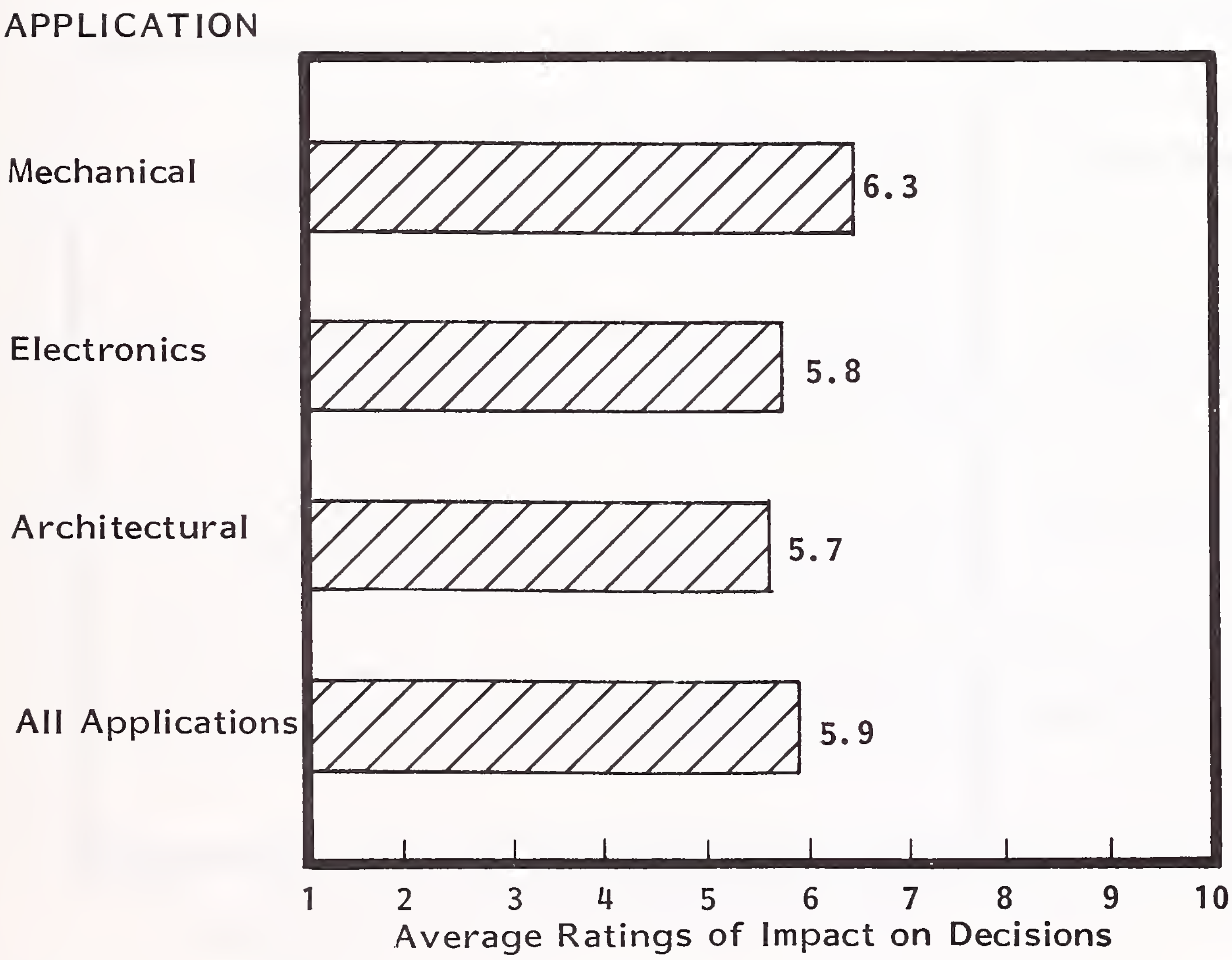


Scale: 1 = No Impact, 10 = Major Impact

*DETAIL APPENDIX A

EXHIBIT III-11

SYSTEM SELECTION FACTORS-
ACCESS TO DATA BASES

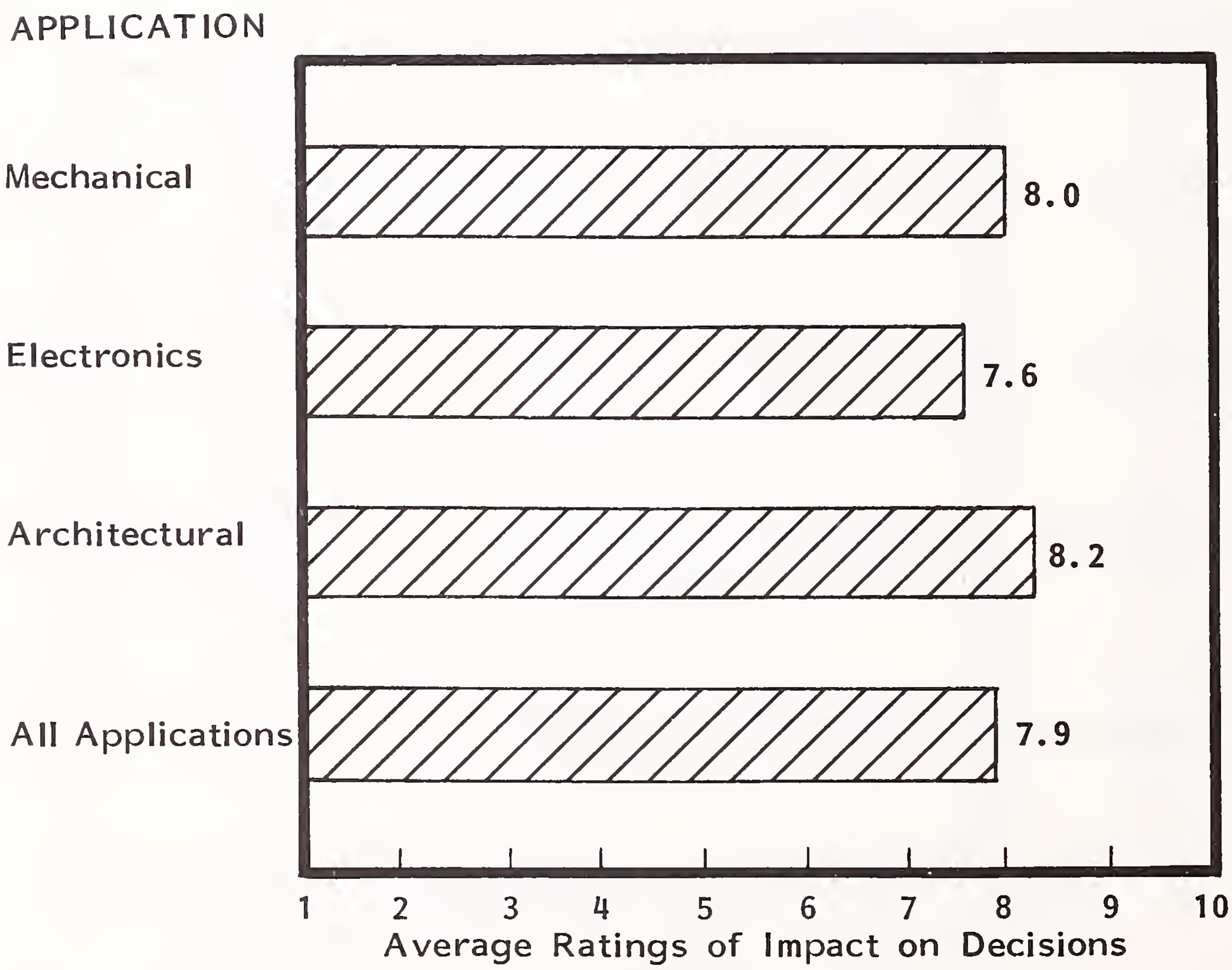


Scale: 1 = No Impact, 10 = Major Impact

*DETAIL APPENDIX A

EXHIBIT III-12

SYSTEM SELECTION FACTORS– SYSTEM FLEXIBILITY



Scale: 1 = No Impact, 10 = Major Impact

*DETAIL APPENDIX A

- This is an unexpected result since the processing capacity of most existing turnkey systems is severely limited; much of the processor's capacity is taken up by graphics functions.

- Two prominent underlying factors in the concern over processing capabilities are:

  - Some users must rely on the turnkey system for analytical processing because it is either their only source or they have limited access to in-house systems or remote computing systems (RCS).

  - "Processing capabilities" is taken by some users to mean total capabilities which would include graphics as well as analytical processing. In this context their concern is usually for the capacity to add workstations in the future without suffering severe degradation.

- While capacity is a major concern, it is also one of the most difficult factors to measure and evaluate because it is a very dynamic factor depending on system loading, the types of concurrent processes, system peripheral complement, configuration, etc.

- "Software capabilities" received a universally high rating, as shown in Exhibit III-9, reflecting the accurate user perception of software as the "heart" of the system.

  - Software not only determines the efficiency of the total system operation, but also determines how effectively the system can be applied.

- Users feel comfortable with software as a factor because of the relative ease with which they can perform feature-by-feature comparisons and analyses. However, testing is required to determine how efficiently the software performs.

- Two other aspects of the software issue were explored in "Future enhancements" and "Access to data bases," as shown in Exhibits III-10 and III-11.

- "Future enhancements" were usually considered by the respondents to apply more to software than hardware.

- While it was rated above mid scale by most, it was not considered critical because users have no guarantee of the timing or extent of future enhancements and can only base their judgements on a vendor's promises and past performance.

- User ratings showed a consensus on the importance of enhancements, but it is too intangible to be given much weight in the final selection decision.

- "Access to data bases" drew mixed reactions from users and, as can be seen in Exhibit III-11, was not very highly rated.

- There was no uniformity of response by company size or industry. Users in similar companies showed widely varying opinions on this factor.

- This is an indication of the level of integration of the design function with other applications (which would require an interface through a data base in most cases).

- Most systems are used for a narrow range of functions and, if they are linked to other applications, usually communicate through relatively straightforward file interchanges and do not rely on more extensive data base capabilities.

- This question could also be interpreted to include "data bases" such as materials properties, components libraries, and construction codes. Even in this context, it is clear that the use of systems still falls into a very narrow spectrum, and users do not see significant value in having access to external data bases.

- The final selection factor surveyed dealt with "system flexibility," as shown in Exhibit III-12.

- Virtually all of the respondent users rated this issue from moderate to very important.

- "System flexibility" is a broad consideration encompassing hardware and software capabilities.

- User comments indicated that this was an important consideration because the future is very uncertain in a number of areas:

  - Integration/interface with other applications, functions, or systems.

  - New uses for the system.

  - New products (both hardware and software).

- The key is software and hardware architecture that allows users to keep their options open and avoid being "locked in."

- Maintenance was not included in the list of selection factors, but was addressed later in the interviews as a separate issue.

  - Maintenance was volunteered as a selection factor by only a small number of users, even though most users considered it a very important issue when questioned specifically about it.

  - This raises serious questions as to the importance given to system selection by many users.

3. SATISFACTION LEVELS

- Most users reported that their systems somewhat exceeded the expectations they had at the time of purchase.

  - Response means ranged between 6.1 and 6.3 on a 1 to 10 scale, indicating higher system performance than anticipated.

  - Users were generally pleased with their systems. Most respondent ratings were between 5 and 8, where 5 "equals expectations."

    - First-time users are generally skeptical of the system really meeting the performance goals set for it.

- No obvious correlations were detected between user satisfaction and company size, industry, or type of product.

- When asked, "If you were to start over again, would you buy from the same vendor(s)?", the responses were:

	Percent Responding "Yes"
Mechanical users	94%
Electronics users	82%
Architectural users	83%

- Almost all of the "no" responses were based on poor vendor support (both hardware and software).

- Even though many users voiced strong complaints about their system or the vendor, they considered their situation to be what they would expect from any other vendor offering similar capabilities.

- One factor bearing on satisfaction is system response time. Overall, slightly more than half the respondents felt their system response time was adequate. "Adequate" ratings were lower in electronics than the other applications, which could be attributed in part to a higher level of design and analysis activities which are processor-intensive.

- Since many respondents had no hard data, response times were often estimated. Response time is an important consideration because it can directly affect productivity as well as discourage use of the system.

- INPUT recommends that system managers make full use of system performance monitoring capabilities or acquire monitoring software to allow them to measure system loading and the system's performance profile (response to certain functions, operations, and commands).

  - System degradation can occur very quickly as workstations are added or the workload shifts to more complex tasks.

  - Some of the degradation may be offset by adjusting operating system parameters (timing), changing the hardware configuration, or scheduling users or certain tasks.

  - Response time should be monitored more closely and not addressed after it has become a critical problem.

4. PRODUCTIVITY

- Productivity gains should be fairly simple to determine since there is basically a one-for-one transfer of operations to the CAD/CAM system.

- However, many respondents had difficulty determining productivity gains over previous methods.

- INPUT attempted to determine overall productivity improvements, as well as gains by, or attributable to, specific functions such as:

  - Design.

  - Drafting.

  - Design analysis.

  - Production planning.

- The general response was that CAD/CAM systems did improve productivity, but the reported improvements varied widely from less than 0% to over 4,000%.

- Some users reported little or no productivity gain, but were still satisfied with their system because it met other needs such as quality, accuracy, and standardization.

- The measurement of productivity appeared to be a very weak area in a number of firms.

  - Very few formal work standards existed for engineering tasks.

  - Tracking was usually done on a gross project or contract basis with limited detailed measurement.

- Drafting yielded the most reliable statistics because of the volume of end-products and the fact that it is a discrete, easily measured process.

  - Responses varied from 0% to 900% improvement.

- A typical response was from 100% to 300%.

- Many considered design and analysis functions to be the most improved by a system, although they were hard pressed to cite firm statistics.

- A complicating factor in determining design improvements is that a CAD/CAM system allows the user to perform more complex designs or even take on entirely new work.

  - The new or more complicated design tasks may mask true productivity gains.

  - Managers should be alert to this situation to explain seeming declines in productivity.

- Productivity is the top concern in most companies, especially as it relates to personnel utilization.

- CAD/CAM managers must establish or update existing methods and standards of measurement.

  - Justifications for additional systems or major enhancements to the original system will usually be based on more complex tasks.

  - Justifications for these new tasks will usually be "softer" and hence subject to closer scrutiny.

  - Typically, the amount of hard standards data available on a task is inversely proportional to the amount of creativity required to perform the task.

5. COSTS

- The mean cost for workstation use in 1981 was $40 per hour (for all engineering applications), growing to $55 per hour in 1986.

- This represents a 6.6% average annual growth rate.

- A number of users predicted their costs would double.

- User cost estimates included labor, overhead, and system costs (maintenance, depreciation, etc.).

- The 6.6% growth projection seems modest until you account for most systems becoming fully depreciated during the period and new systems or add-ons being priced lower due to technology advances.

    - The most significant cost increase is projected to be personnel.

- Salaries for engineers are expected to increase dramatically over the next five years with an added premium on those with CAD/CAM experience.

- Labor cost increases have the potential for negating a significant portion of the productivity gains forecasted in system justification analyses.

6. SYSTEM LOCATION AND USE

- CAD system workstations are still the domain of specialists.

    - In some cases they are dedicated operators who enter designs, data, or changes from the engineers.

    - The remainder are engineers who are dedicated (or nearly so) to a workstation.

- Sixty percent of all respondents reported "specialist" operators.

  - The lowest incidence was in electronics at about 50%, while architectural reported the highest at 80%.

- Workstation operations are too complex at the present time for infrequent use by engineers.

  - An average training period of three to four weeks was reported to train a new user for "initial use" such as system prompts and functions, menus, commands, and use of files.

  - Training to complete proficiency took an average of 20 weeks with a number of responses in the six-month to one-year range.

  - The longest training periods were reported by electronics users.

- Many users felt that the human interface aspect or "system friendliness" was a barrier to wider use of the systems. This should be a major area of concern for vendors as well as users evaluating new systems.

- Eighty percent of the workstations were located in a central facility as opposed to being co-located with the functional groups.

  - Ambient lighting and distance limitations from the central processor were two key factors.

  - Relaxed requirements on workstation placement will be required for systems to become more widely used throughout a company.

7. DATA SECURITY

- Mechanical and architectural users were polled on the need for data security and rated it about mid scale (5.5), growing slightly in importance in five years to 6.9.

- Data security was generally rated higher by the large firms, with very low ratings by small- and medium-size companies.

- Smaller firms felt the system-provided data access provisions were adequate, while large firms were concerned with a broad range of security considerations.

  - System access.

  - File access.

  - System accounting.

  - File backup and recovery.

- While security is not perceived as a major issue today, it will grow rapidly in importance as CAD/CAM becomes a more integral and valuable part of company operations.

- CAD/CAM managers are advised to consult with their company's data processing organization to establish procedures for:

  - File backup and recovery.

  - Data archiving.

  - Off-site or protected storage.

  - Disaster planning.

8. INTEGRATION

- Integration has become the most widely discussed topic in the CAD/CAM field. One could assume from all of this activity that integration is a readily available capability; but in reality, it is in the early stages of development and has a long way to go before it is an off-the-shelf product offering.

- Integration, defined as the tight coupling of applications so that data is transferred or further operations initiated automatically or with minimal intervention, represents the optimal utilization of a CAD/CAM system.

- CAD/CAM systems offer the opportunity to automatically capture product data at its point of origin, the design process.

  - Automatic capture eliminates error-prone manual processes.

  - It reduces the time for data to reach processes downstream in the product cycle.

- Many companies have, or are implementing, automated manufacturing, planning, management, and administrative systems.

  - Failure to interface their CAD/CAM systems will limit the total corporate system to the accuracy and time constraints of the manual processes involved in the interfaces.

- The generation of numerically-controlled (NC) machine tool tapes is a rapidly growing example of integration.

  - The NC application program accesses the part geometry from the CAD data base and automatically produces a cutter location file, based on tool and motion parameters entered interactively by the workstation operator.

- The operator can then view the machining operation dynamically on the display, in multiple views, to verify the operation and check for collisions or clearances.

- When the operation is correct, the operator can initiate post-processing to generate a control tape for a particular machine tool.

- The next step in integrating these two functions will be to automatically download directly to the machine tool controller or a direct numerical control system.

- The preceding is a prime example of the integration of design and manufacturing functions.

  - The all too common interface, the drawing, is eliminated.

  - The operator or NC programmer directs the system in the transformation of data, rather than performing it manually.

  - Checking can be performed more thoroughly and in less time.

  - Total time from design to production is shortened considerably.

- Vendors are becoming increasingly vocal about their abilities to offer integrated systems.

- A careful examination of some of the claims reveals that the basis for integration is there.

  - System exits and "hooks" are provided for the user to interface with other applications.

- Programming macros and other tools are provided to accommodate interfacing.

- Communications access methods are available, but in a number of reported cases leave much to be desired.

• Some vendor offerings are true integrated applications (such as the NC example), but their implementation can be self-defeating.

  - Most turnkey systems reach their system processor capacity at six to eight workstations.

  - Implementing additional applications on a system already burdened with graphics, design, and drafting functions can seriously degrade response time.

  - If the applications were developed by the turnkey vendor, then moving them to an external processor is extremely difficult, if not impossible.

  - The options are to tolerate degradation, compromise the extent of integration, or install another system. None of the options are attractive to users.

• Independent software packages for use on a satellite processor are an alternative, but the linkage to the turnkey system can be a major effort and usually will be the user's responsibility.

  - Turnkey vendor workloads for standard product support are so heavy today that it can be difficult to secure their involvement.

• In-house development of integrated systems is progressing very rapidly in a number of major corporations, but it will remain out of reach of the smaller companies for some time.

- Users felt that integration has made little progress to date and will make significant gains over the next five years, as shown in Exhibit III-13, but will still be very short of full integration.

- Electronics applications have made somewhat better progress, partly because of their longer and more intensive use, but are not projected by the users to progress much beyond the levels anticipated in 1986 by the other application segments.

- Mechanical and architectural users were asked to rate a number of factors on how great an obstacle they represented to integration. Their responses are shown in Exhibits III-14 through III-16.

- All companies, regardless of their size, must address the integration issue. As their use of CAD/CAM matures, the need for other applications interfaces will increase.

- Integration crosses many organizational boundaries and requires careful planning as well as close cooperation.

    - User concern about integration should be not only that it can be done, but who will do it.

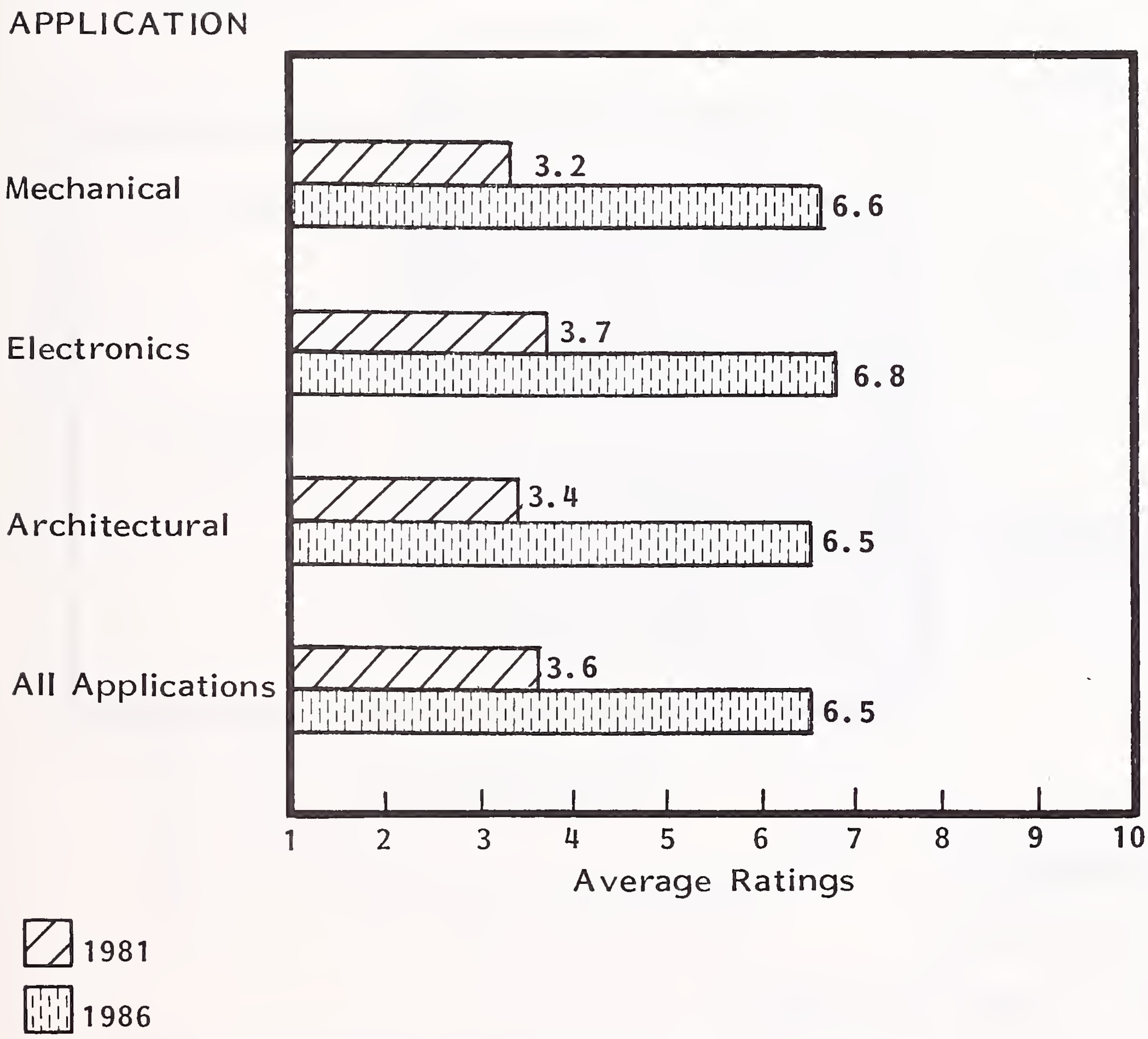
    - It must be determined who will be responsible for activities such as planning, setting standards, programming, testing, support, and management?

    - The organizational issue will generally force integration responsibility to a corporate level.

- When asked how the trend toward integration would affect various organizations, user responses were quite mixed.

EXHIBIT III-13

STATUS OF CAD/CAM INTEGRATION

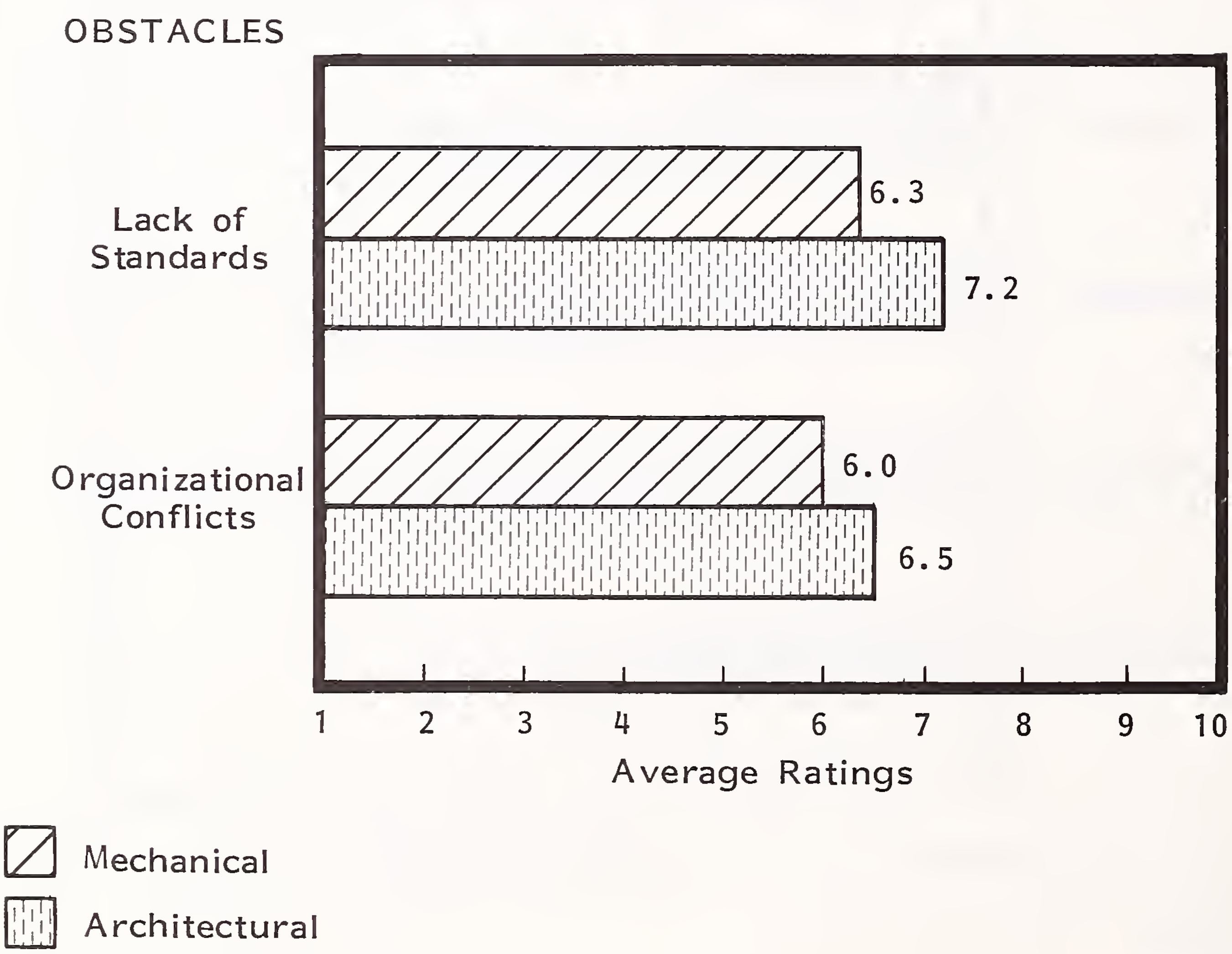


Scale: 1 = No Progress, 10 = Completely Integrated

*DETAIL APPENDIX A

EXHIBIT III-14

CAD/CAM INTEGRATION OBSTACLES-
LACK OF STANDARDS AND ORGANIZATIONAL CONFLICTS

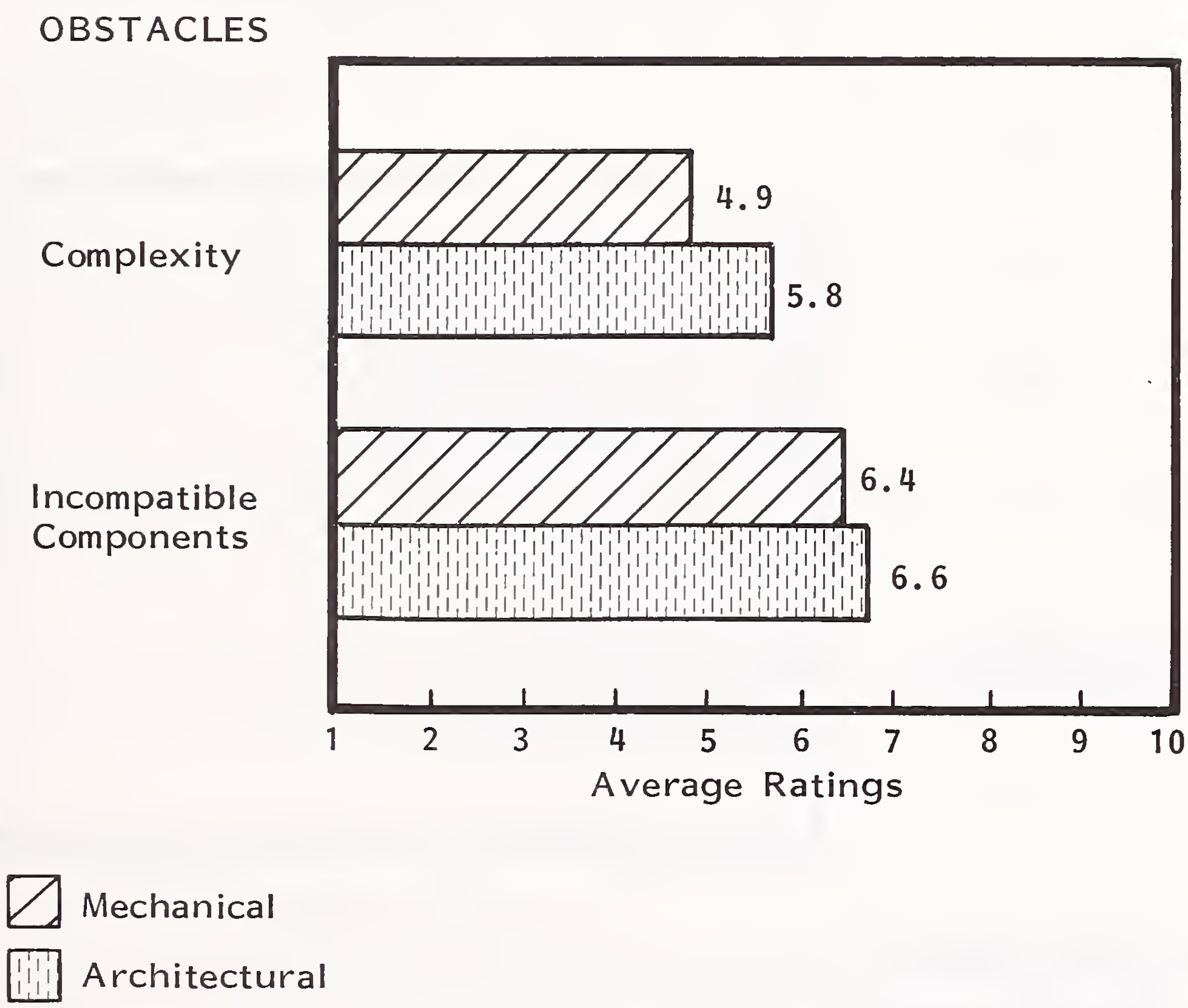


Scale: 1 = None, 10 = Major

*DETAIL APPENDIX A

EXHIBIT III-15

CAD/CAM INTEGRATION OBSTACLES-
COMPLEXITY AND IMCOMPATIBLE COMPONENTS

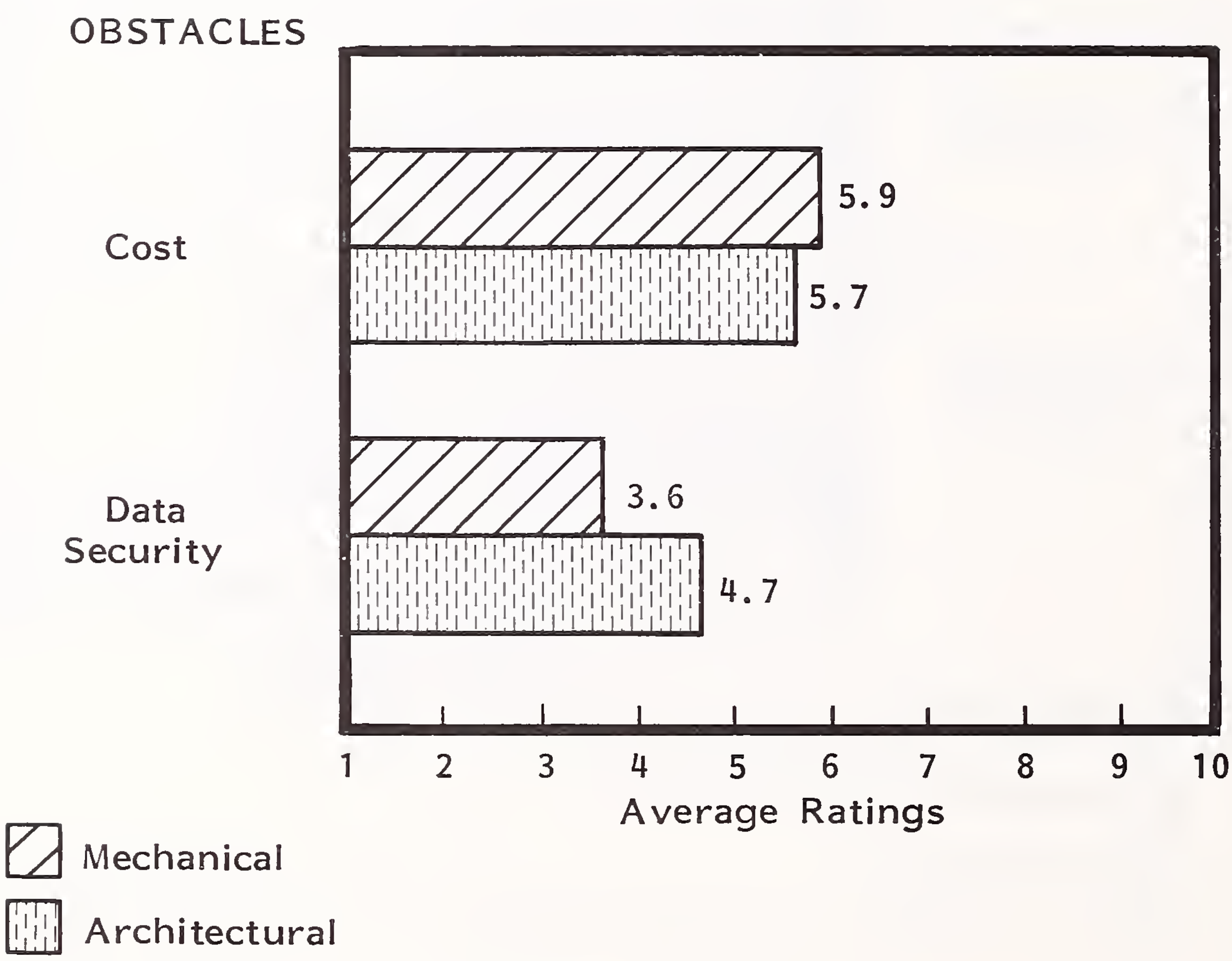


Scale: 1 = None, 10 = Major Ratings

*DETAIL APPENDIX A

EXHIBIT III-16

CAD/CAM INTEGRATION OBSTACLES-
COST AND DATA SECURITY



Scale: 1 = None, 10 = Major

*DETAIL APPENDIX A

- Organizational conflicts were given moderately high ratings (Exhibit III-14), but may be underrated by the respondents.

- Most agreed that closer working relationships would have to develop and communications improve (between engineering and manufacturing, for example).

- Some users felt that traditional DP organizations would diminish in power as processes and data bases were distributed, while others felt they would increase as DP became the owner/operator of the main data base.

- Data processing will play a key role in integration because of its software and systems experience.

  - Applications knowledge is important, but the critical factor in the success of integration will be the design of the total system and its interfaces.

  - Integration depends heavily on a centralized data base which is an area of strength and expertise in most DP organizations.

  - Systems programming capability does not exist in engineering organizations. They must rely on the DP department.

- Vendors also play a key role in the integration issue.

  - They will either promote integration through the adherence to standards and provision of interfaces or impede it with a "protectionist" attitude.

- Users must make vendors aware of their needs for system flexibility, accessibility, standards, documentation, and support.

- Integration should be a major and recurring topic at user group meetings.

- Users must find out where the vendors stand on this issue.

- Vendor response is a critical factor in the integration issue: failure to respond to user needs could have serious adverse effects on their market success.

• The development of additional, downstream applications and their subsequent integration by turnkey vendors is seen as a problem area.

  - Most turnkey vendors are already heavily burdened by their growth.

  - Significant additional investments will be required for staffing to develop and maintain this new software.

  - Turnkey vendors with large corporate parents such as Calma (GE) and Applicon (Schlumberger) seem to be the most likely to succeed in broadening their capabilities.

• Major mainframe vendors entering the CAD/CAM market could have a definite advantage in dealing with integration:

  - Mainframe systems have extensive data management capabilities.

  - Mainframe vendors have experience in the integration of diverse applications, including manufacturing planning and control.

  - A wide range of interfaces have been developed for peripherals, inter-processor communications and data collection devices such as shop floor terminals.

- Mainframe vendors will have a significant advantage over smaller turnkey vendors.

  - They can offer both the central system plus smaller CAD/CAM systems or a single, large scale, multi-use system.

  - They occupy a position of high visibility and usually have good credibility within the corporation.

  - Their support capabilities are more extensive, which is both a practical as well as a marketing advantage.

  - They will generally be perceived as being more knowledgeable in a wider range of data processing issues than turnkey vendors who are seen as narrow-field, graphics specialists - an important distinction when integration is at issue.

- Accepting data from diverse turnkey systems can present problems to mainframe vendors, but can also be to their advantage.

  - Until standards are established, this will be an opportunity for mainframe vendors to encourage their customers to stay with their product lines rather than mixing vendors.

  - Mainframe vendors will be able to apply more resources to the data compatability problem, thereby gaining a strategic and competitive edge over the smaller turnkey vendors.

- The capability for accepting data from or passing data into an integrated data structure will soon become an important criterion for system selection.

  - The lack of standards was one of the highest ranked concerns of respondents (Exhibit III-14).

- Users are becoming sensitized to the importance of data integration either through direct experience or from the increasing amount of literature on the subject.

- It is INPUT's opinion that many respondents are underestimating the difficulty and complexity of integration. Ratings in the five to six range do not reflect a significant concern (see Exhibit III-15).

    - Many are not familiar with data processing systems and thus have a simplistic idea of the integration process.

    - Many systems are only used for the more fundamental functions and thus have limited requirements for integration. Users are not anticipating their future needs when their use becomes more involved.

- "Incompatible components" were ranked higher than "complexity" as an integration obstacle by respondents (Exhibit III-15). It is not clear why incompatibility was not considered to be a subordinate, contributing issue to complexity. The same can be said for lack of standards and organizational conflicts.

- Complexity involves a number of considerations:

    - Selection of software and hardware components.

    - Establishing plans for the overall integration effort and the individual application projects.

    - Securing the backing and involvement of internal and external organizations and then managing their efforts.

    - Linking the various hardware and software elements.

    - Providing on-going management and planning of the integration effort.

- Cost was only given moderate ratings by the respondents (Exhibit III-16). One possible interpretation of this may be that the standards and incompatibility issues are seen as someone else's problem (the vendors) and organizational conflicts will not add to the cost of integration. In reality, any obstacle to integration will be costly to the user, either as a direct cost or an opportunity cost.

- Data security was not perceived by respondents as a major obstacle to integration (Exhibit III-16). Most users felt that adequate system safeguards existed to prevent unauthorized outside access to their data and systems.

- One major obstacle to integration lies within the user community itself which has varying needs.

  - Companies vary widely in the way they perform their internal operations.

  - Existing systems, methods and procedures, and data bases will pose problems when users attempt to integrate them with generalized vendor packages.

  - Users will be forced to make compromises to minimize costly and resource-intensive customizing efforts.

  - Careful trade-off will be required.

  - Users must accept the fact that no standard vendor packages will ever completely fit their needs.

  - Vendors must also remain aware of this situation and take a flexible approach in the development of systems and applications.

- INPUT agrees with the respondents that integration will progress over the next five years, but not to any great extent.

- The introduction of data and file interchange standards will have a positive impact when they finally become accepted and implemented.

- The active involvement of major computer manufacturers, with their extensive resources and systems experience, could accelerate the development of standards and integration tools and techniques.

- Integration will take place on a piecemeal basis as vendors and users feel their way through this very complex issue.

• Integration will proceed slowly over the next three to five years and then accelerate rapidly.

  - Vendors will learn from their involvement with major firms who are developing their own integrated systems.

  - The most difficult task will be generalizing and simplifying integration methodologies so that they will apply to the middle market.

  - Users must resist the pressure to rush into untested vendor offerings (the "beta test" temptation).

• In any case, integration will never be a simple, "off the shelf" set of products because of the diversity of user and industry requirements.

C. GRAPHICS DEVICES

• The ability of CAD systems to improve productivity stems from the increased amount of information that can be communicated to the user in graphical form.

- INPUT investigated the adequacy of displays used in interactive processes and the impact of permanent record output devices such as plotters or computer output microfilm (COM).

1. DISPLAY TECHNOLOGIES

- Display technology was the only study topic dealing with hardware per se. The workstation is the most user-sensitive system component because it is the point of actual interface between system and user. The performance and functions of most of the other hardware components are either transparent to the user or are masked by software.

- Display image quality can have a definite impact on satisfaction and productivity. Both are influenced by image quality (resolution, contrast, flicker, etc.) and speed. Visual separation (color or shading) can also improve productivity by increasing the information clarity and content.

- Display technology is advancing rapidly due in large part to memory and microprocessor developments. Users can now consider higher resolution and local image dynamics displays without paying a correspondingly higher penalty in central processor loading.

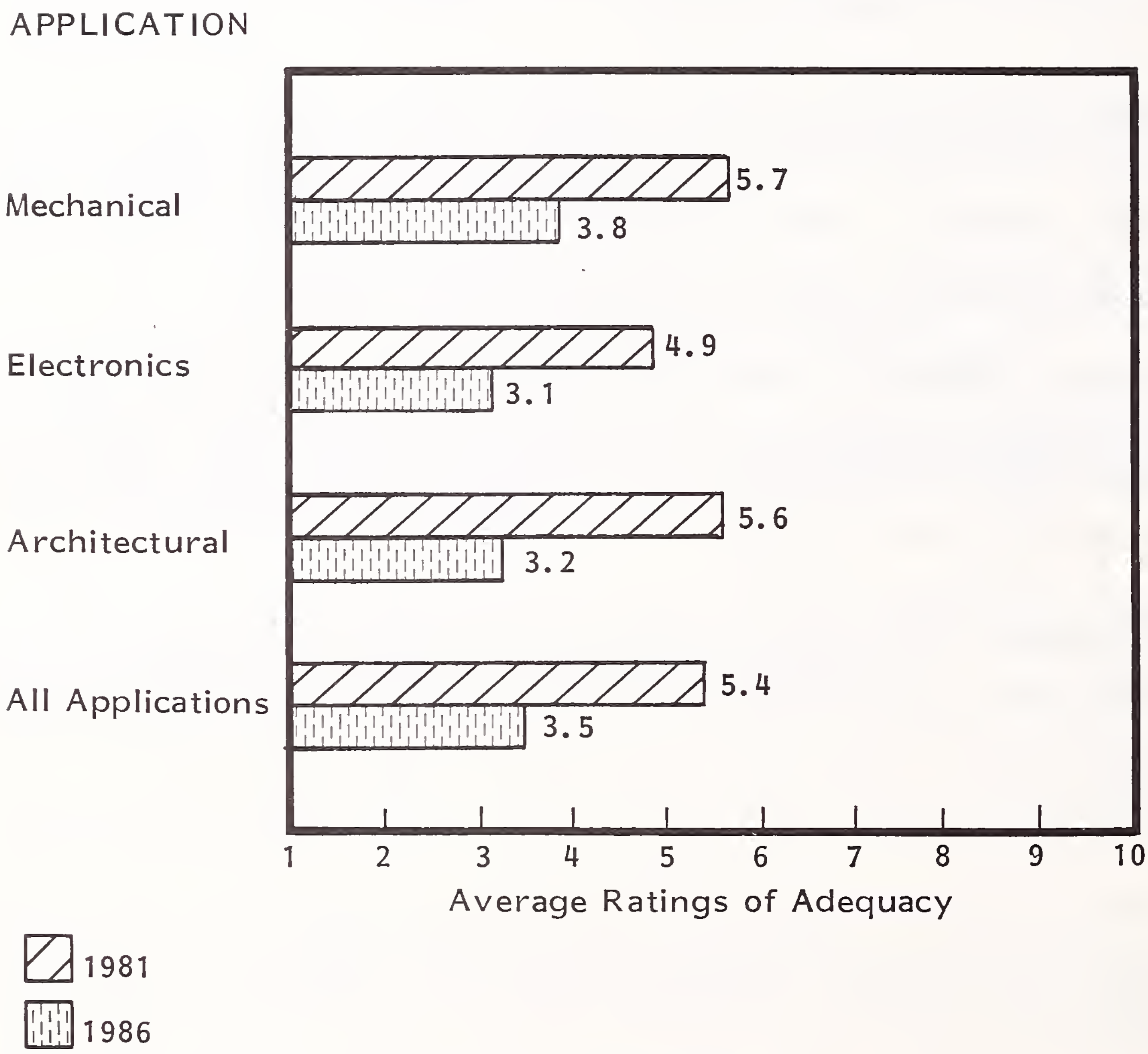
- Respondents were asked to rate the three display technologies (storage, calligraphic (stroke refresh), and raster scan) as to which best serves their needs now and in five years. The results are shown in Exhibits III-17, III-18, and III-19.

- Storage tubes were perceived to fall significantly behind the other technologies in five years for all application areas due to their slow speed and lack of dynamics.

- Electronics users clearly preferred raster scan displays because of their refresh time insensitivity to the number of elements being displayed; a definite factor with high density screens such as integrated circuits.

EXHIBIT III-17

ADEQUACY OF STORAGE TUBE DISPLAYS

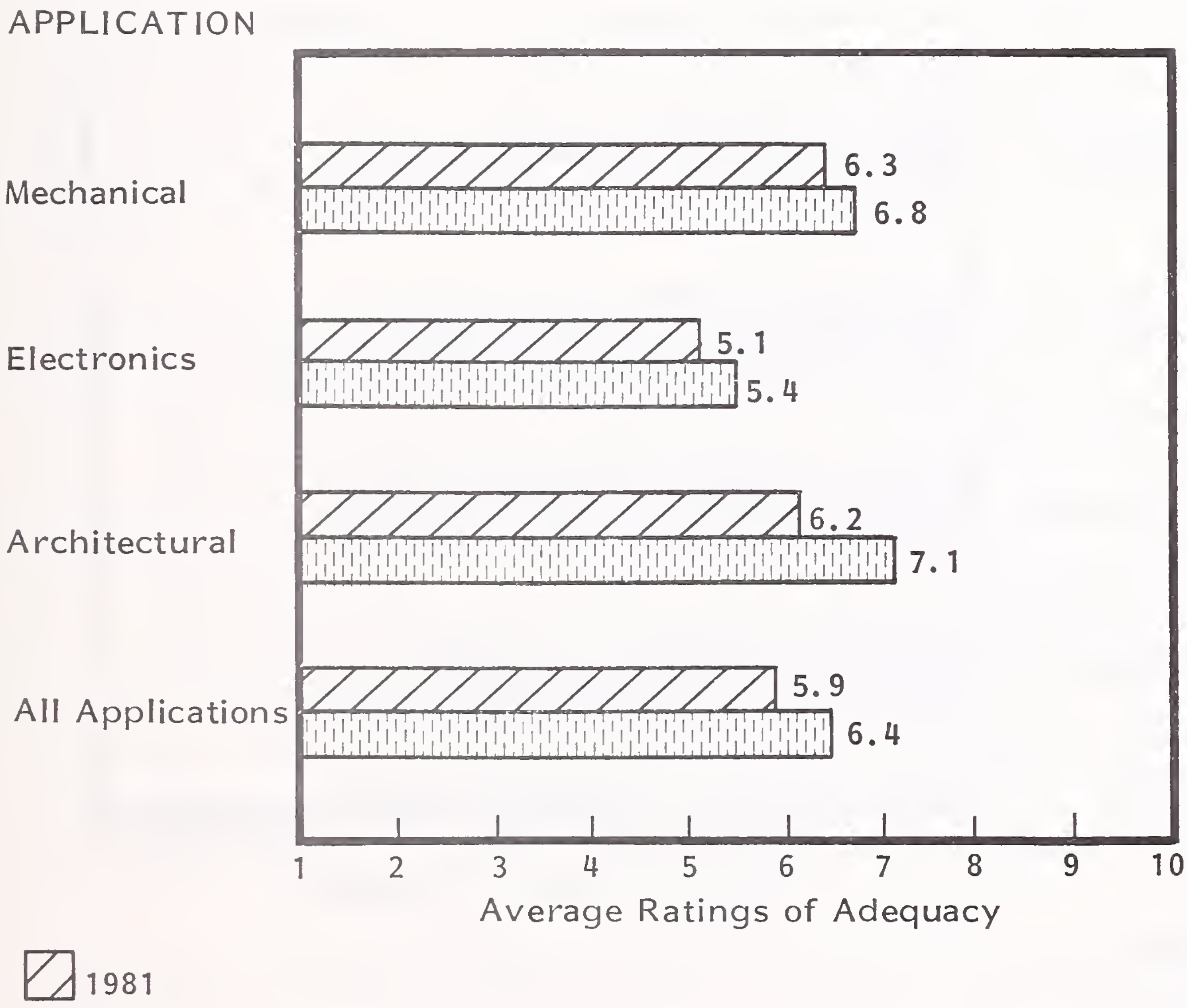


Scale: 1 = Inadequate, 10 = Exceeds Needs

*DETAIL APPENDIX A

EXHIBIT III-18

ADEQUACY OF STROKE REFRESH DISPLAYS

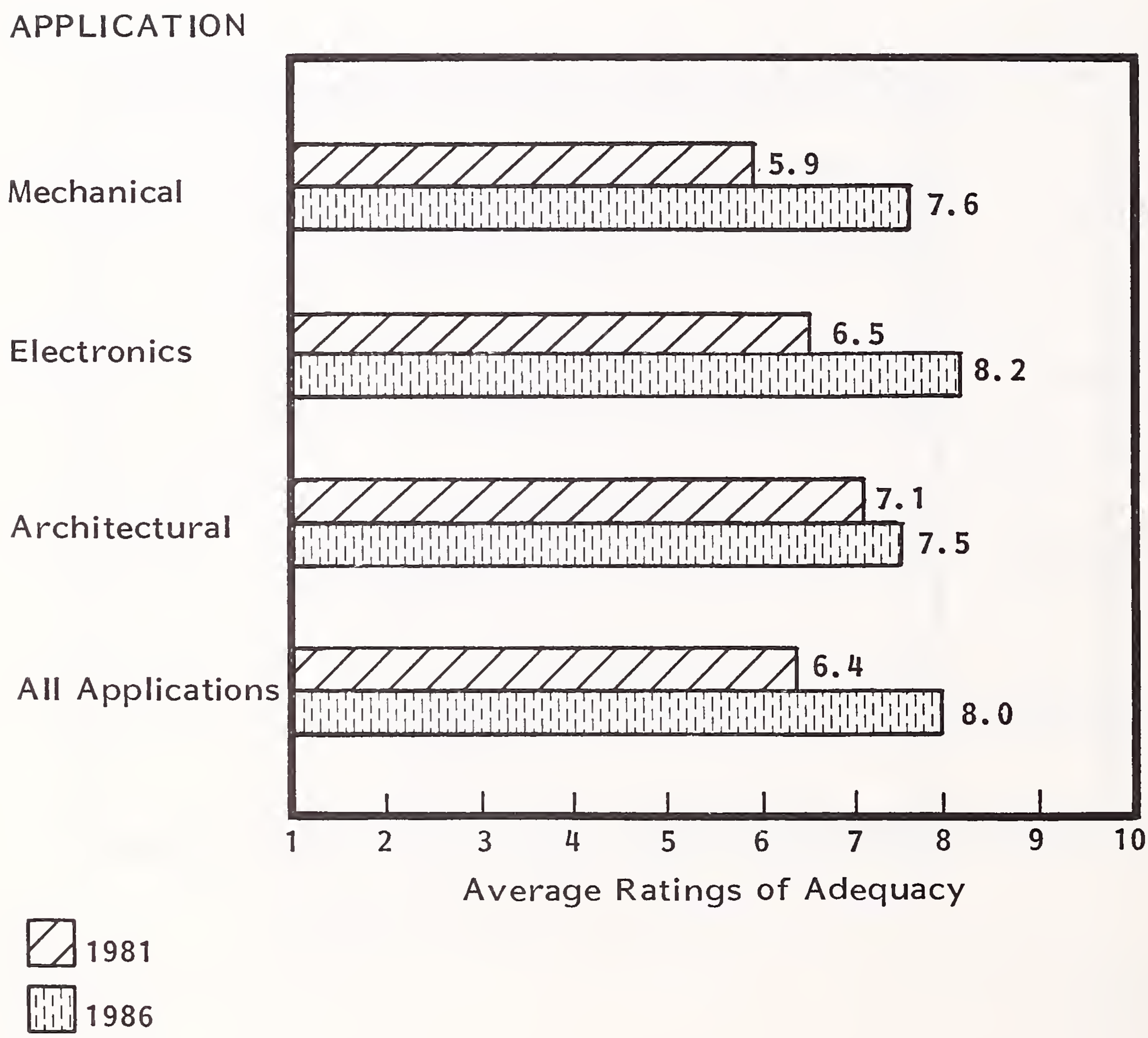


Scale: 1 = Inadequate, 10 = Exceeds Needs

*DETAIL APPENDIX A

EXHIBIT III-19

ADEQUACY OF RASTER SCAN DISPLAYS



Scale: 1 = Inadequate, 10 = Exceeds Needs

*DETAIL APPENDIX A

- Some mechanical and architectural users were also concerned with display refresh times, but expressed concern over present raster scan resolutions (especially the aesthetics of diagonal lines).

- Higher resolution displays will make raster scan the most popular type across all application areas by 1986.

- Stroke refresh displays held their moderately high ratings with mechanical and architectural respondents through 1986 because of high quality images.

2. COLOR

- Color is being heavily promoted by system and component vendors; however, many users rated color as a low to moderate requirement today, as shown in Exhibit III-20.

- Color is expected to become much more important in five years.

    - The more experienced users are either using color now or will be installing color workstations in the very near future.

    - Some electronics users report that color is very important in distinguishing circuit board levels, component groups, or circuit functions.

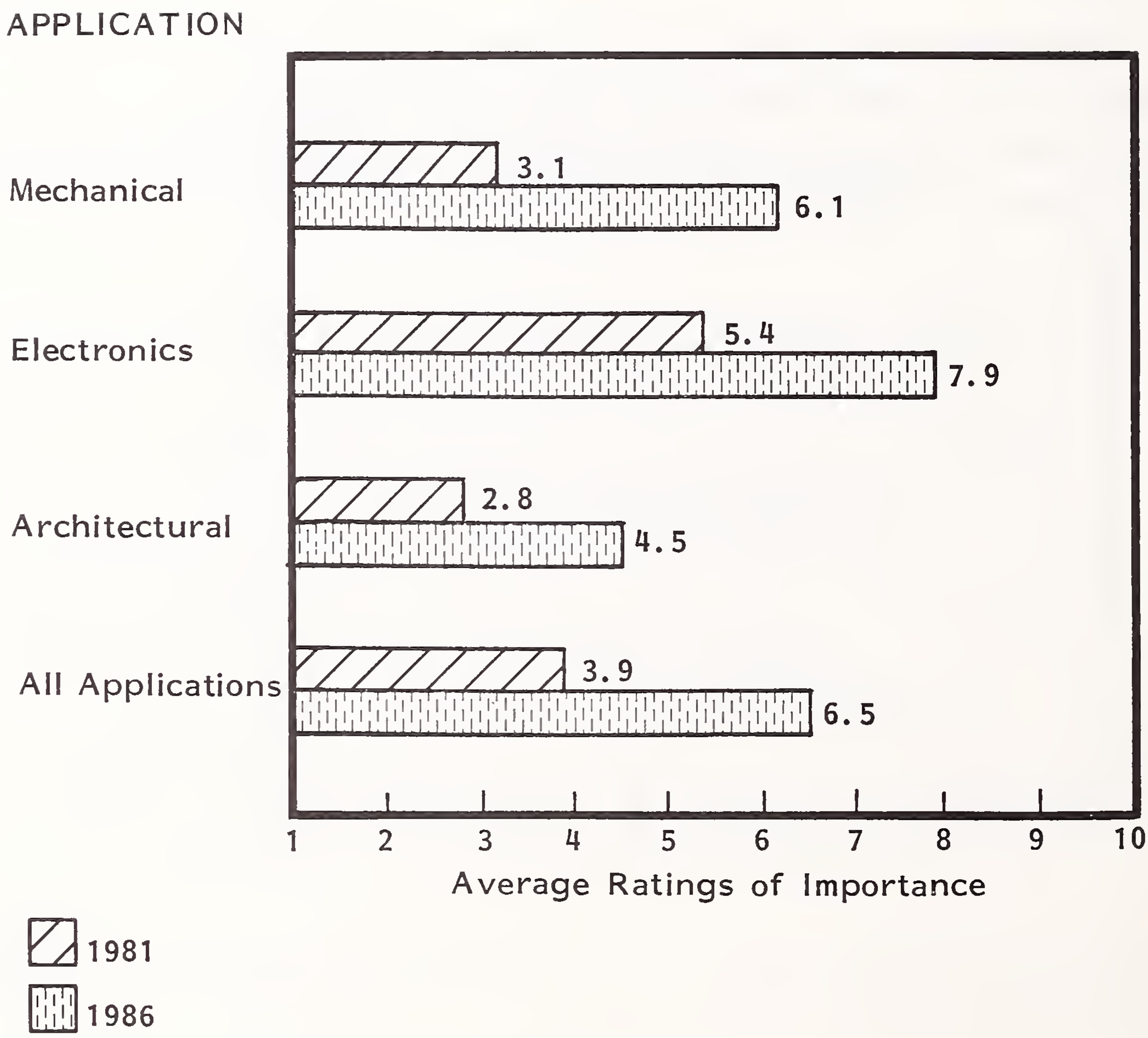
- Mechanical and architectural users are not willing to trade resolution for the other advantages at the present time. Resolution is more of a problem with color displays and will continue to be a factor in their acceptance.

- Some users expressed concern that the increased use and acceptance of color workstations would lead to strong pressure for color hardcopy.

    - Color hardcopy technology is still fairly immature and expensive.

EXHIBIT III-20

IMPORTANCE OF COLOR DISPLAYS



Scale: 1 - No Requirement, 10 = Essential

*DETAIL APPENDIX A

- Cost, reliability and quality of color output devices could be a significant barrier to increased use of color displays.

- The use of color will grow dramatically in the next five years and will most likely outpace the projections of the users.

  - Color greatly increases the information transfer between the system and the user. The increased clarity of information presentation will further eliminate mistakes due to misinterpretation.

  - Thus far it is a latent need because many users have not progressed beyond using the basic system capabilities.

  - The technological problems of resolution, quality, reliability, and cost of color devices should be resolved at about the same time that broad user needs begin developing.

3. HARDCOPY OUTPUT

- Hardcopy output, specifically drawings, is an area of concern for mechanical and architectural users.

  - Plotting and drawing reproduction are significant production bottlenecks.

  - Hardcopy is increasingly expensive to reproduce, distribute, and store.

  - There is always the danger that updates will not be distributed to all parties, resulting in costly and time consuming errors.

- CAD/CAM systems are ideal for information storage and dissemination.

  - The information is always current.

- Information can be displayed graphically and manipulated for further interpretation or understanding.

- Transmission is virtually instantaneous.

- With all of the obvious advantages, it would seem logical to assume that CAD systems could significantly reduce the amount of hardcopy produced.

- Users were less than enthusiastic about the probability that conventional drawings would become obsolete, as shown in Exhibit III-21.

  - They assumed about a 50/50 chance for obsolescence by 1986 and about a 70% chance by 1990.

  - Some felt very strongly that there was little likelihood of it ever happening.

- Drawings, instructions, and notes will never become totally obsolete.

  - The cost and portability of hardcopy cannot be equalled for remote locations.

  - Display station costs would have to decline significantly to allow them to be widely distributed throughout a facility.

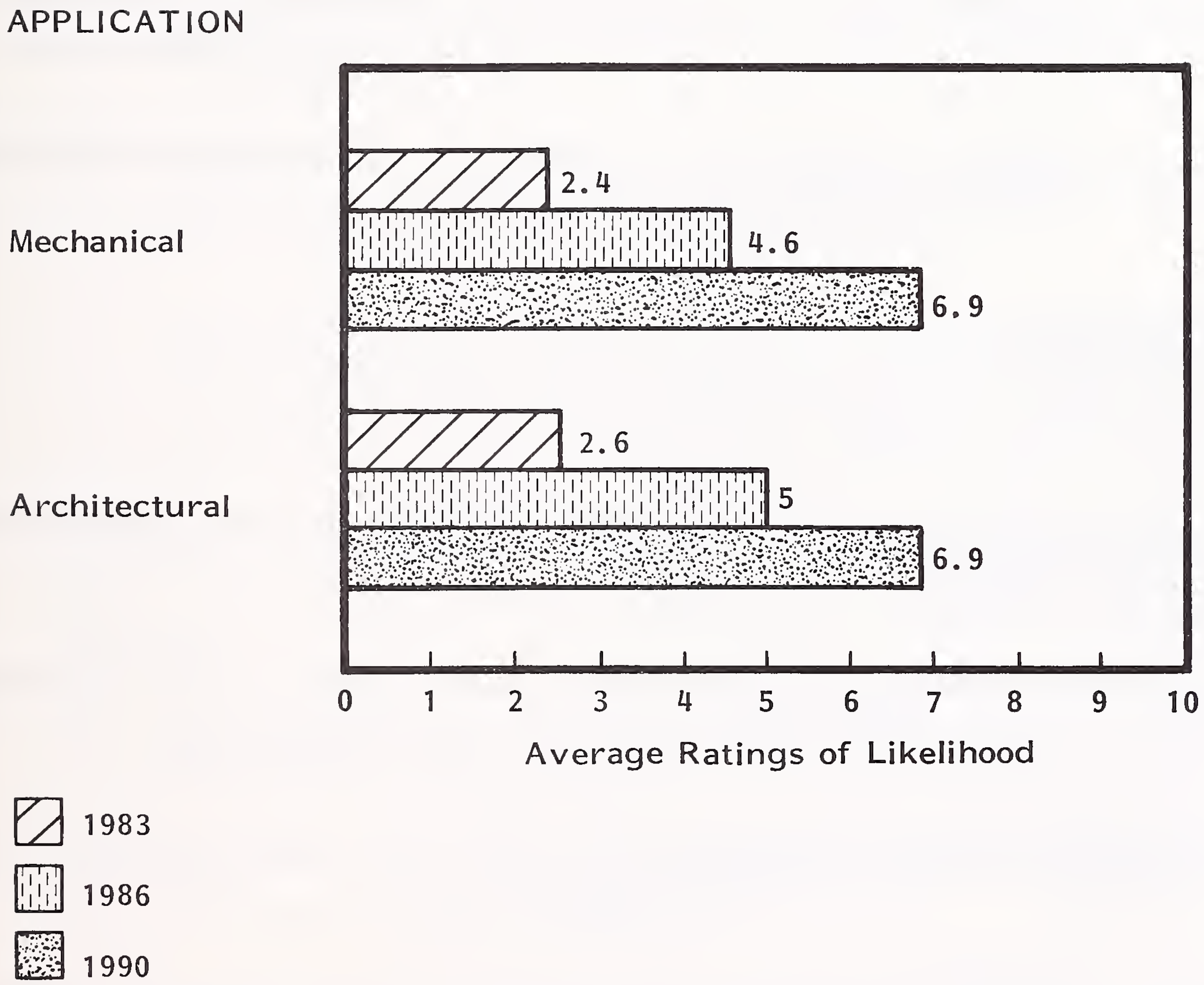
  - Outside organizations may not have the capability to accept data via electronic media.

- Users are strongly encouraged to thoroughly evaluate the use of hardcopy in their organizations.

  - The most prevalent reason for using hardcopy is inertia; people are accustomed to using it and will continue to demand it long after it is truly needed.

EXHIBIT III-21

LIKELIHOOD OF CONVENTIONAL
DRAWING MEDIA OBSOLESCENCE



Scale: 1 = Impossible, 10 = Certain

*DETAIL APPENDIX A

- The continued use of hardcopy can identify areas or procedures which should be changed to reflect the efficiencies available through the use of CAD.

- Resistance to change may also indicate either a need for training and education on CAD capabilities or a lack of confidence in the system.

- The issue of hardcopy obsolescence is a prime example of the collision of a new technology with the inertia of ingrained habits.

    - It is localized and made more visible with hardcopy, but it can exist in many other areas affected by the installation of a CAD/CAM system.

    - Managers must be alert for resistance at all levels of the organization and offset it with training and education.

D. SOFTWARE

- Software is the most important element in a CAD/CAM system and represents the greatest problem area for vendors and users alike.

- Software development is a highly skilled craft; as such, it is time consuming and, considering the shortage of experienced people, very expensive.

- Software technology has improved, but still lacks the advantages found in hardware.

    - There have been no technological breakthroughs that have made software orders of magnitude less expensive to develop as we have seen in hardware; in fact, software development costs are increasing.

- There are very few components packages that vendors can acquire and use to build their software systems.

- Efforts are underway to develop programming support tools, program generators, and more powerful languages, but it will be a slow, evolutionary process.

- Software development studies conducted by INPUT show a serious shortfall in the number of people entering the data processing field, as shown in Exhibit III-22.

  - As the CAD/CAM market expands, it will place additional demands on the programmer supply.

  - Vendors that are just now beginning to respond to market pressures to expand their applications offerings will be impacted.

  - Large users who are considering in-house developments (either because of unique application needs or frustration with vendor progress) will find themselves in stiff competition with vendors for qualified people.

- Software is an area of major concern and will continue to be so for many years. It is a highly redundant effort with no significant transfer of technology.

I. SOFTWARE ADEQUACY

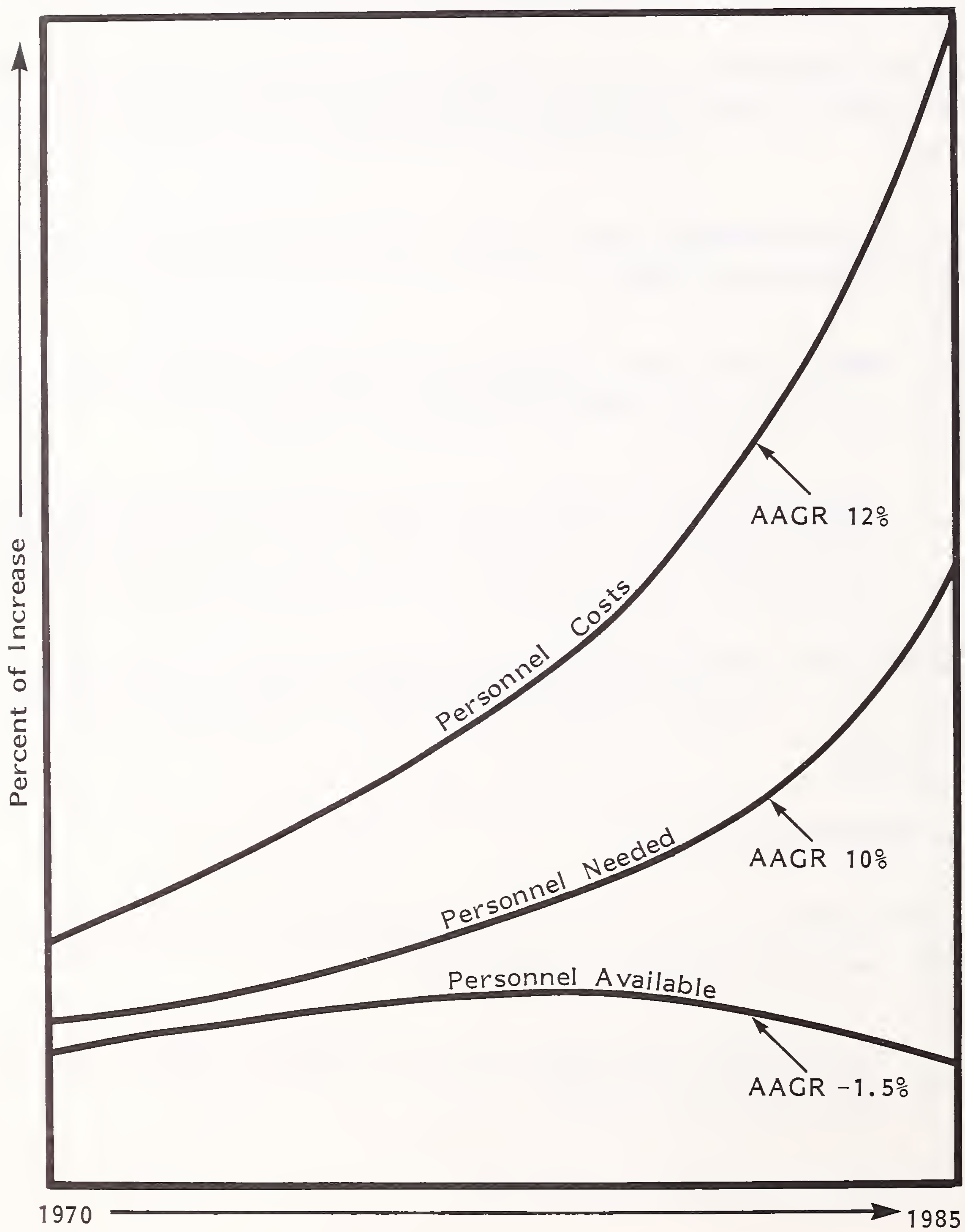
- Users were asked to rate the overall adequacy of their software now and in 1986. The findings are shown in Exhibit III-23.

  - Overall, ratings were slightly above mid scale for 1981 and showed some improvement by 1986.

- The grouped statistics can be misleading.

EXHIBIT III-22

ANTICIPATED PERSONNEL COSTS AND SHORTAGE

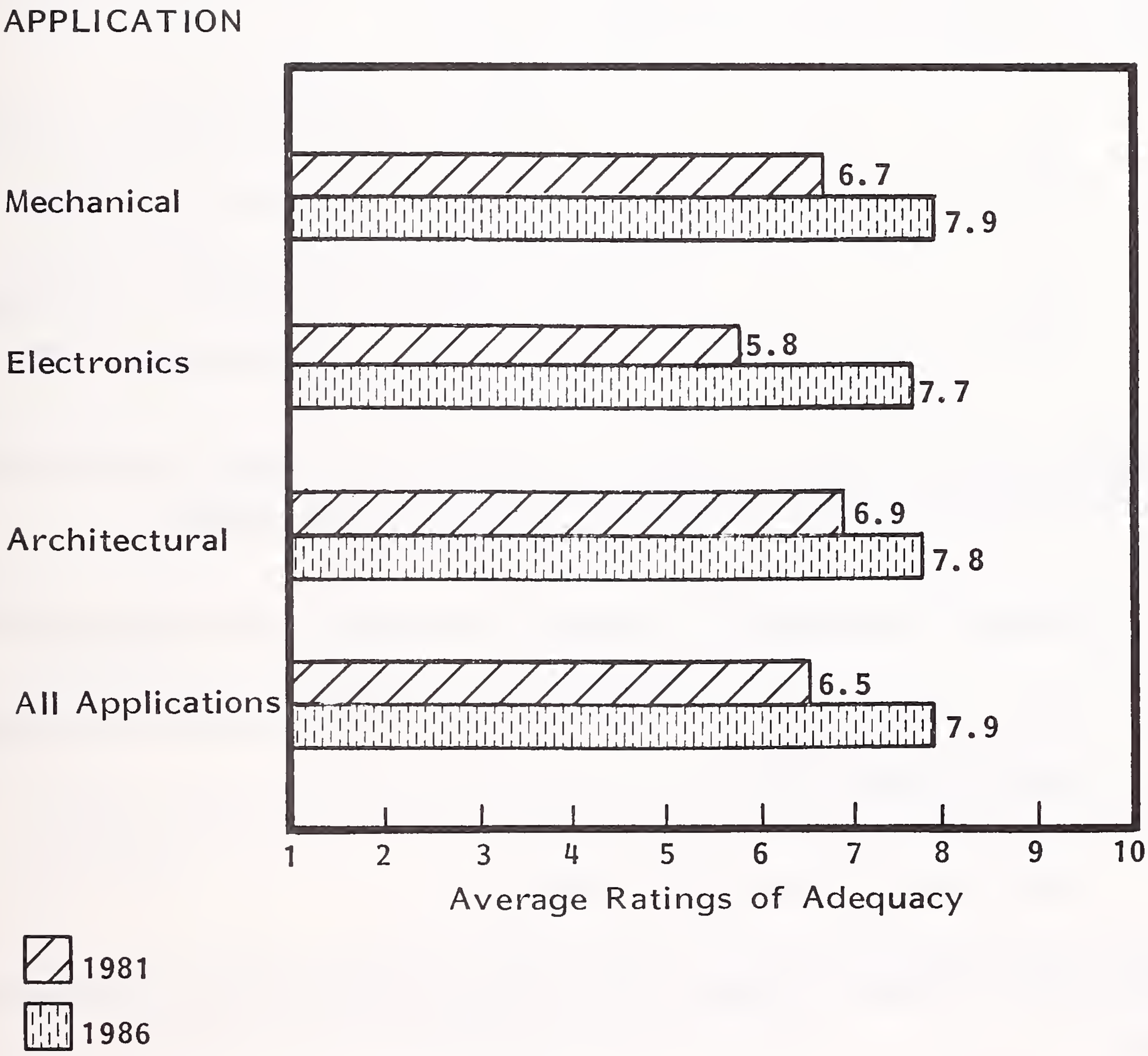


Source: Input's Multiclient Study Improving the Productivity of Systems and Software Implementation, November 1980.

*DETAIL APPENDIX A

EXHIBIT III-23

SOFTWARE ADEQUACY



Scale: 1 = Very Poor, 10 = Excellent

*DETAIL APPENDIX A

- Electronics users' ratings reflect a moderate satisfaction level, but large firms have expressed strong dissatisfaction with vendor offerings and have launched major in-house efforts.

- Mechanical users appear to be more satisfied than electronics users, but they too are shifting efforts in-house in the larger companies.

- Architectural users are generally not pushing the limits of vendor-supplied software and are the most satisfied today.

• Adequacy ratings for current software should not be construed to reflect the users' attitude toward the total software situation.

    - They expect software to be improved, but expressed concern over the adequacy of new software packages they will be using in the future.

    - Users are very aware of vendors' software development and support problems and do not see any clear resolution in the foreseeable future.

• Smaller users that have no internal development or support resources and are forced to rely wholly on vendors are becoming very frustrated.

    - New system releases with unresolved errors were mentioned frequently.

    - Late releases, constant slips, and broken promises were repeatedly mentioned frustrations.

    - Poor documentation is also a problem.

• Users must thoroughly evaluate the software capabilities of a potential vendor.

- Given that the software performs the listed functions, the user should determine if the vendor has an applications-experienced staff to enhance and maintain it.

- Most vendors' expertise clearly lies in the area of graphics, graphics-related functions, and system internals.

  - Users expressed concern that vendors do not have sufficient in-depth applications knowledge to support them or ensure that their needs will be met as an application evolves.

  - This situation will be aggravated as vendors attempt to bring more applications to the market.

- Users reported using a number of independent software packages in conjunction with their turnkey or in-house system.

  - Most were for simulation or extensive analysis.

  - Virtually all were run on a system other than the turnkey processor due to limited computing capacity.

- Generally, the independent, specialized packages were given higher ratings than the CAD system supplier's software.

- Vendors should seriously consider all decisions to supply application-specific software.

  - The added burdens of specialist staffing for application development, maintenance, and support can be excessive.

  - Joint ventures with established specialty firms may be more profitable in the long run.

- Parochialism and protectionism are dangerous attitudes for system vendors.

  - Users do not care if their applications software was developed by their system supplier as long as it meets their needs and is adequately supported.

  - Vendors who restrict or discourage the use of other vendors' software on their systems are doing a great disservice to their users and will ultimately pay a high price in the marketplace for their attitude.

  - Users do not expect system vendors to be experts in an application unless they position themselves as one by developing an application.

2. STANDARDS

- Industry standards for hardware interconnection, data media, and communications have existed for some time.

- They were developed over a period of time and through the combined efforts of users, vendors, and the government.

  - In cases where agreement could not be reached, a major vendor's standard became the de facto industry standard.

- CAD/CAM standards are a major concern to users.

  - Many feel locked in to a single vendor and want the flexibility to transport files among different systems.

  - Transportability of data between companies is becoming an issue as CAD/CAM becomes more widespread.

  - A lack of data standards will inhibit the development of integrated systems by requiring multiple unique interfaces.

- In spite of the concern over standards, most users are not even aware of the work being done to develop them, much less being involved in their development.

  - Approximately two-thirds of the users polled by INPUT were not familiar with the proposed standards.

  - One user commented, "I don't care which standard is adopted, just so they come up with one."

- INPUT recommends that all users get involved in the standards issue. If they do not have the time or expertise to become deeply involved, they must at least make their position known.

  - An excellent vehicle for communicating with vendors is through vendors' local and national users' groups.

  - Users' groups have proven to be influential in guiding standards and in some cases have written them.

  - Professional societies are also very good vehicles since they tend to be independent of significant vendor influences.

- Some vendors do not regard standards as being particularly advantageous:

  - Conforming to standards usually requires additional software development efforts.

  - It is not always in their best interest to give customers ready flexibility in system-to-system interfaces.

- As the CAD/CAM market develops, vendors will be forced to adopt industry standards to remain competitive.

- Major users (customers with multiple systems) are demanding the flexibility to move data from one vendor's system to another.

- The federal government will play a key role in CAD standards as it did in data processing.

• Major U.S. turnkey vendors have either announced Initial Graphics Exchange Specification (IGES) support or will in the very near future.

• European vendors and users responding to the INPUT study see GKS (Graphics Kernel System) as the leading standard.

• The diffusion of U.S. and European markets and technologies will force vendors to support multiple standards in order to compete in international markets.

• A number of vendors and major users expressed a very pessimistic view of the standards situation today:

  - They do not see the government or industry associations effectively setting standards until they secure the support and involvement of the leading vendors.

  - Some feel it will be the late 1980s before a practical set of standards is fully accepted and demonstrated by being fully supported by vendors.

• Since the subject of CAD standards is relatively new, INPUT foresees an evolutionary process of development and acceptance.

  - It is still early enough to accommodate a number of compromises in the leading specifications (IGES, Siggraph-Core, GKS).

  - While 64% of the respondents expressing an opinion on standards feel that IGES will become the final U.S. standard, INPUT feels that the

final, leading standard will be a combination of those under consideration today.

- In all likelihood, there will be several industry standards due to unique requirements and special interests of vendors, industries, and the government.

- Some users see the development of standards as a cure-all to the systems interface problem, while in reality there will always be dialectical problems associated with vendor interpretations or implementations; however, even these problems will be minor compared to a lack of standards.

- IGES appears to be the leading U.S. specification due to its advanced state of development and support.

  - IGES is a project of the Air Force Integrated Computer-Aided Manufacturing (ICAM) Program.

  - It is supported by funding from the Army, Navy, Air Force, and NASA.

  - The National Bureau of Standards has been contracted by the Air Force ICAM Program to direct and coordinate the IGES effort.

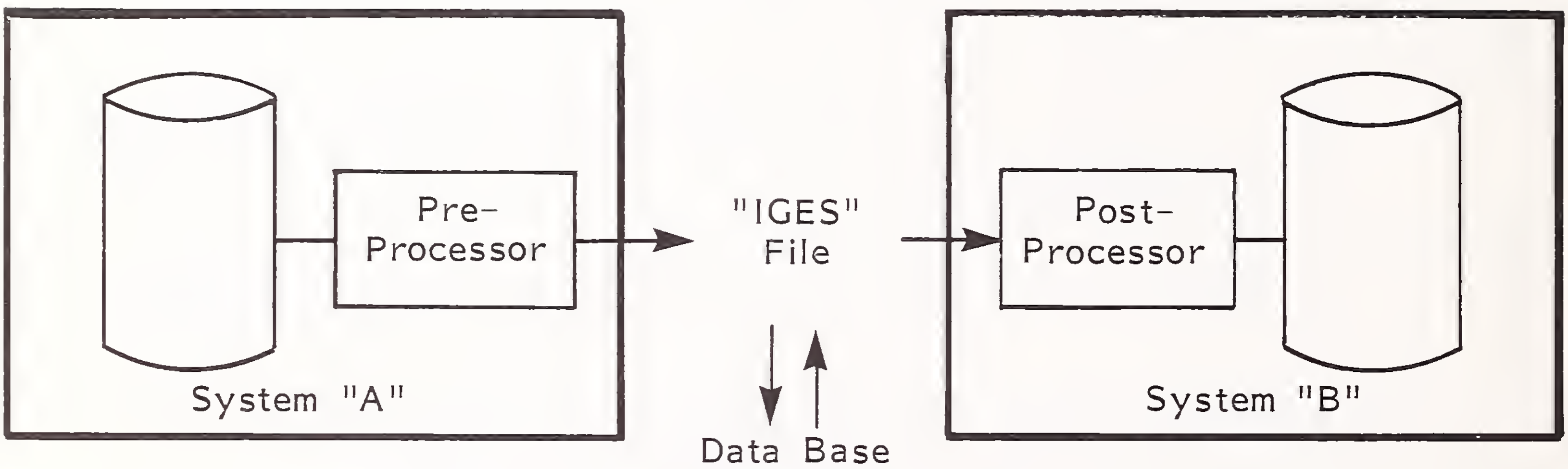
  - Over 50 companies are involved in the IGES program.

  - IGES has been selected as the first four parts of a five part proposed ANSI standard. The final draft of the ANSI standard has been approved and should be published by the end of 1981.

- The functional implementation of IGES is illustrated in Exhibit III-24. Vendor-developed processors are used to convert files in their system's format into a standardized format or vice-versa.

EXHIBIT III-24

FUNCTIONAL IMPLEMENTATION OF IGES



REPRINTED FROM: INITIAL GRAPHICS EXCHANGE SPECIFICATION (IGES) VERSION 1.0, NATIONAL BUREAU OF STANDARDS DOCUMENT NBSIR 80-1978(R)

- Communication through a neutral file requires a vendor to develop only one set of pre- and post-processors to interchange data with all other vendors.

- Users can also archive their data in the standard format to eliminate future problems in restoring the data on different vendor systems or newer operating system releases from the same vendor.

• INPUT advises all clients to obtain information on IGES so they may keep abreast of developments:

  - First time users are advised to obtain:

    . National Bureau of Standards Technical Briefing on IGES.

    . Document number NBSIR 81-2297.

  - The final draft of the IGES specification as incorporated by ANSI is also available from NBS (no document number - request by name).

  - The IGES Newsletter is published on an as-needed basis by the IGES project and is available at no charge.

  - The above documents may be ordered through Ms. Joan Wellington, A-353, Building 220, National Bureau of Standards, Washington, DC 20234.

  - The NBS Technical Briefing on IGES is also available from the National Technical Information Service (NTIS), Springfield, VA 22161.

• IGES is a specification for communicating drawing and geometry data and is oriented toward mechanical and architectural processes. Some electronics users expressed concern that IGES is not applicable to their needs and the electronics area could fall seriously behind in standards development.

- An interesting classification of what IGES is and is not is reprinted below from the National Bureau of Standards Document NBSIR 80-1978(R) IGES Version 1.0:

"It is important to note that IGES was created to meet an immediate need. IGES is a specification and not a standard. Efforts are underway to coordinate the IGES with standards making bodies. In particular an IGES working group is being organized to (among other tasks) coordinate with the various American National Standards Institute (ANSI) committees and other standards efforts. It is expected that the IGES will be one of the many important steps in the complex procedure required to produce a national standard. (INPUT emphasis.)

"In the short time span from the start of the IGES effort, several misconceptions about IGES have developed. In order to clarify them, the following lists of what the IGES is and is not are presented.

- IGES is a specification for the exchange of data between CAD/CAM systems.

- IGES is a vehicle for archiving data from a CAD/CAM system.

- IGES is designed with the technical aspects of several current CAD/CAM systems in mind. Thus the translation from vendor systems to IGES and vice versa will not be one for one, but should be feasible.

- IGES is based on the Boeing CAD/CAM Integrated Information Network, the General Electric Neutral Data Base, and a variety of other data exchange formats which were given to the committee.

- IGES is the best specification that could be produced in the time frame permitted. While it is not a copy of any of the exchange formats presented to the committee, it has the advantage of the experience and knowledge gained in their production and use.

- IGES is a set of geometrical, drafting, structural and other entities. Thus it has the capability to represent a majority of the information in CAD/CAM systems.

- IGES is extensible. Several definition mechanisms have been provided to permit IGES to be expandable. A working committee has been set up to coordinate expansions and to correct errors.

- IGES is not a national standard.

- IGES is not a data base structure.

- IGES is not designed for the technical aspects of any one of the currently available CAD/CAM systems.

- IGES is not perfect, or the solution to all data exchange problems between CAD/CAM systems.

- IGES is not a carbon copy of any of the exchange formats given to the technical committee.

- IGES is not a stand alone contractual specification for a deliverable product.

- IGES is not a complete specification of all the data in all CAD/CAM systems. Thus there may be a loss of data or structural information in the translation to and from IGES.

"In summary, IGES is not perfect, it will not solve all the information exchange needs of CAD/CAM systems, and it will need future extension beyond its current definition. However IGES goes a long way toward alleviating the current data exchange problem, and is a significant response to today's needs."

E. VENDOR SUPPORT

- Because of their capacity for greatly increasing productivity, CAD/CAM systems quickly become a critical component in the design/engineering cycle.

  - This criticality of function raises the vendor support issue to high levels of visibility within the user organization.

- Vendor support (specifically maintenance) was hardly mentioned by the respondents as a factor in system selection, yet it was given a high weight in future purchase decisions.

  - This underscores the discovery by users that vendor support is indeed a very important consideration.

  - Overall, respondents said that 38.3% of their future purchase decisions would be based on the quality of maintenance a vendor provides.

- INPUT cannot generalize the support statistics of any given vendor because of the wide variations reported by users.

  - Vendor response times ranged from hours to days depending on the location of the user installation.

  - Vendor support is highly localized and seems to depend more on the stability and management of the local vendor office than on other factors such as number of installations, size of area covered, or type of applications supported.

- The most frequent concern expressed by users was the competency of vendor support people.

- Demand for qualified hardware and applications support people is far exceeding the supply.

- The employee turnover rate of people from vendor to vendor and from users to vendors is very high.

- Tenures average less than one year and turnover rates are exceeding 50% per year for some vendor field support organizations.

- One regional users' group has taken the approach of not permitting a vendor to use member sites for demonstrations or benchmarks if the vendor has defaulted on a support commitment.

  - Vendors can expect users to become more forceful in pressing for more responsive support.

  - Users can expect the support situation to continue in a state of flux for some time as vendors struggle with rising personnel costs and increasingly limited availability of skilled personnel.

- Vendors are turning to telephone and other remote support concepts to alleviate labor and cost pressures.

  - Regional and national hotlines are being offered as a more responsive alternative to on-site calls.

  - Centralization allows wider use of support specialists and a more intensive environment for training of support personnel.

    - Indications are that overall support levels increase with centralized support, but many users are skeptical and have taken a wait and see attitude.

- Users can expect to see more vendor products involving remote hardware and software diagnostics as well as incentives for users to run their own periodic diagnostic tests and limited self-maintenance.

- Declining equipment costs (and therefore unit profit margins), coupled with increasing support personnel costs, are forcing component suppliers such as display manufacturers to consider offering only depot maintenance.

- Users are becoming more concerned with system availability.

  - There is a tolerance period when users will accept lower reliability from a new system, but this period is becoming shorter as users look more at CAD/CAM as a mature industry.

  - CAD/CAM system availability is generally below that experienced with data processing systems.

  - Several factors will raise the users' level of expectation to the very high 90% ranges:

    - Increased utilization of CAD systems.

    - Increasing criticality of CAD/CAM in overall company operations.

    - Involvement of the data processing organization (as a result of integration), with its higher standards for availability.

- The support situation will continue to be aggravated by the shortage of skilled people and will not improve dramatically over the next several years.

- Users should adopt a realistic attitude and develop practices to minimize the impact of system downtime. One practice is to work closely with the vendors and establish good communications with them.

- A number of respondents have developed adversary relationships with their vendors which were becoming counterproductive for both parties. The vendor can usually benefit from active feedback from the user; in its absence he will assume that there are no problems.

- Support data collection and record keeping can be key in improving support. Accurate records not only help identify product weaknesses, but also weaknesses in the support organization. They are also invaluable in resolving disputes.

- If multiple systems or locations are involved, data should be directed to a central source so that the entire support situation can be monitored and effective leverage applied to resolve problems.

- Vendor users' groups can also be utilized as sources of comparative support performance data and a forum to bring problems to the vendor's attention.

I. HARDWARE AND SOFTWARE

- Generally, respondents gave hardware and software maintenance quality about the same ratings, as shown in Exhibit III-25.

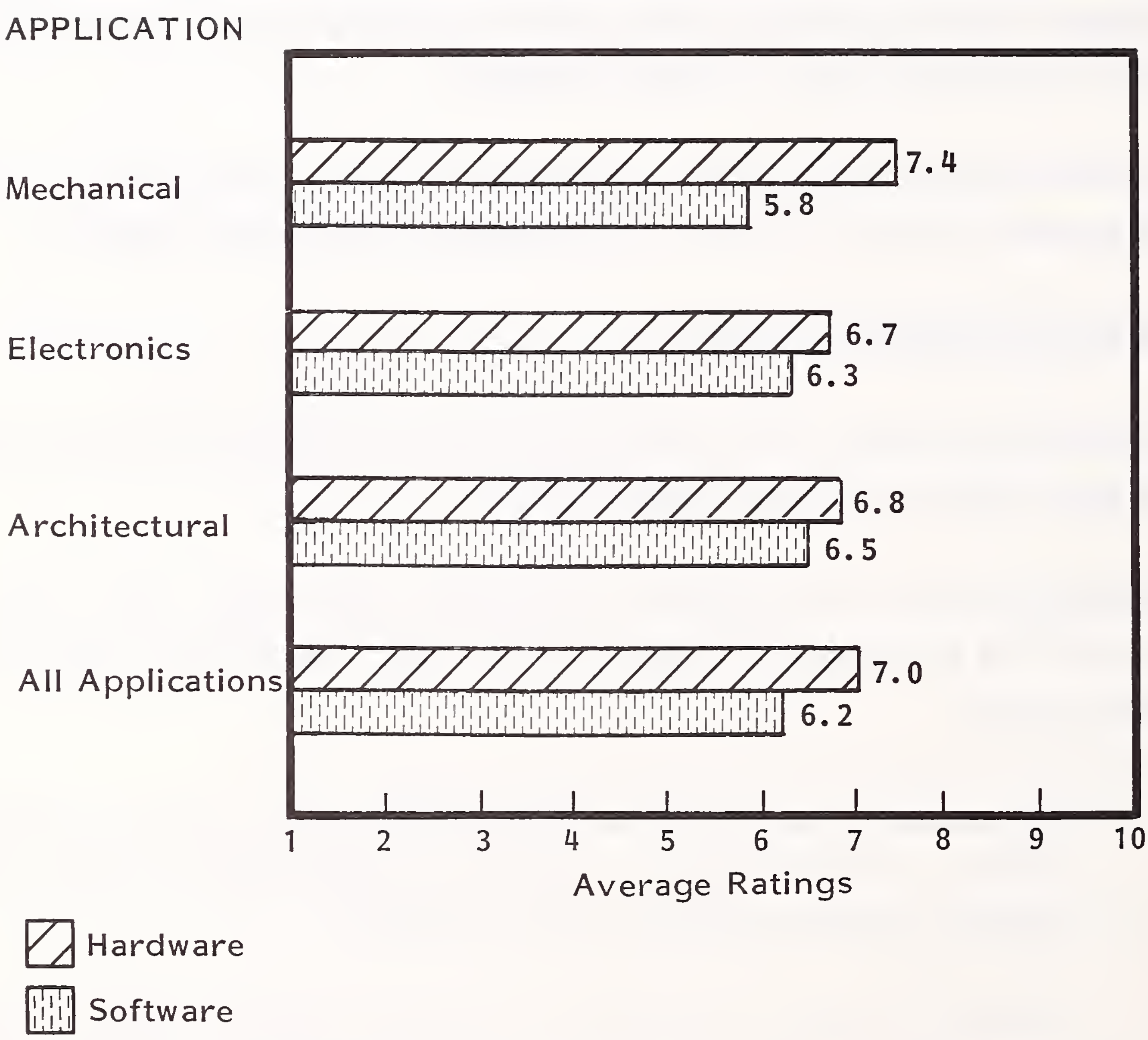
- Mechanical users rated hardware maintenance quality higher than software (7.4 and 5.8 respectively), while electronics and architectural rated them about the same.

  - One explanation is that electronics software is more mature, while the average architectural user is effectively underutilizing his system and thus not exposing significant software problems.

  - Mechanical applications software is receiving relatively intensive usage considering its level of maturity; therefore, users are identifying problems faster than vendors can resolve them.

EXHIBIT III-25

QUALITY OF MAINTENANCE



Scale: 1 = Inadequate, 10 = Superior

*DETAIL APPENDIX A

- A small number of turnkey users surveyed by INPUT have begun performing their own hardware maintenance.

  - This becomes economical at about three turnkey systems (large configurations) or where CAD/CAM and other systems maintenance can be combined.

  - Reasons cited include concern over declining vendor field engineer capabilities, slow response times, and delays caused by parts availability.

  - As CAD/CAM systems become more integrated into the overall company operation, we will see more users turn to in-house maintenance although it will most likely never be a significant percentage of the installed base.

  - As the market continues to grow, there will be opportunities for third-party maintenance companies.

- Users are concerned about the future direction of software maintenance for a number of reasons:

  - Most software is vendor proprietary and hence cannot be maintained by outside parties.

  - Industry growth is straining the supply of qualified software support people.

  - As vendors bring out more and increasingly complex applications packages and systems, they are forced to extend their resources to new limits.

- The most common software maintenance complaints centered around new releases:

- "Very slow - never close to the promised release date."

- "Tired of receiving everything as a 'beta test' site; unfortunately, it's the only way to get anything on a timely basis."

- "Documentation is either terrible or non-existent on new releases."

- "Always full of bugs and we end up going back to the previous release until they get it fixed. Tired of being a guinea pig."

- While nearly all users must rely on the vendor for support of the system and applications software, there are areas where support can be obtained from in-house development groups and outside contractors:

  - Utilities and special purpose software such as accounting and utilization programs, cost estimating, project control, and scheduling.

  - Interface packages such as system communications, data base interface, and special peripheral handlers.

- Software vendors are becoming aware of the opportunities to interface their products to turnkey sytems.

  - This activity can be expected to accelerate as vendors are forced to concentrate on their primary products.

  - Systems software interfacing is becoming less of a problem as CAD vendors rely more on standard operating systems from the CPU manufacturers.

2. USER GROUPS

- Ninety-four percent of the users surveyed belong to a user group.

- Overall, users rated the effectiveness of the users' groups in achieving their goals at 6.2 on a 1-10 scale. There was no significant difference among the ratings by application groups.

- Comments indicate that users see their participation as their best (if not only) way to have unfiltered communications with the vendor home office.

  - One user called his group a "coordinated voice crying in the wilderness to the manufacturer."

  - A number of respondents consider users' groups to be vendor managed, but still participate in order to have an opportunity for direct contact with vendor management.

  - A repeatedly stated benefit was the opportunity for peer communications among users.

IV PRODUCTS AND SERVICES

IV PRODUCTS AND SERVICES

A. OVERVIEW

- Early CAD systems (circa mid-1960s) required some of the largest and most expensive mainframe computers to perform relatively straightforward tasks by today's standards.

- Rapid and dramatic improvements in cost/performance ratios due to hardware technology advances have fueled the growth in CAD/CAM systems use.

- In spite of the attention given to the CAD/CAM industry, it is still in its infancy:

  - Total industry revenues represent only a small percentage of the total data processing market.

  - There is very little product differentiation among the various vendors' offerings, although some is emerging now.

  - Commercially available CAD/CAM systems have just begun to progress beyond the functions of drafting and basic design.

  - "Spin-off" products are still embryonic and turnkey systems are still the preferred product delivery mode.

- The CAD/CAM market is following the classic patterns of development, with penetration and proof of applicability at the higher levels of use in large companies, followed by acceptance by smaller companies.

- Downward migration rapidly broadens the primary and secondary markets, but also introduces entirely new considerations for the vendors as will be seen later.

- The industry is entering a new stage of development:

  - Rapid increases in user sophistication are placing new demands on the established vendors.

  - The market has grown to the point where it is attracting the attention of major computer manufacturers.

  - Hardware costs have dropped to a level where new companies can afford to enter the market.

- The developmental stage of the CAD/CAM market, taking place over the next five years, will be marked by sweeping changes in technology, market participants, product mixes, and impact on user organizations.

B. CURRENT PRODUCT OFFERINGS

1. TURNKEY SYSTEMS

- Turnkey systems dominated the INPUT user sample:

Application	Percent Using Turnkey Systems
Mechanical	72%
Electronic	91%
Architectural	97%

- The remainder of the systems were either commercially available software running on in-house mainframes or custom-built systems, usually developed by the user.

- As could be expected, only the major automotive, aerospace, and electronics firms had sufficient resources to develop or put together custom systems.

- The distribution of turnkey vendors among respondent sites is shown in Exhibit IV-1. This exhibit only reflects the presence of a vendor at a user site and not the number of systems installed; as such, it is more representative of a vendor's penetration of an application area by biasing out multiple installations and differences in the size of the vendors' installed populations.

- Lockheed's CADAM system was included in the turnkey exhibit even though it could also be classified as a software package.

- It is interesting to note that CADAM is installed at more mechanical user sites than any turnkey vendor except Computervision.

  - Even though the total number of CADAM installations is lower than most of the turnkey vendors, the implications of a widespread IBM presence in the mechanical sector are clear.

- Computervision is dominant among the mechanical respondents, Calma clearly led in electronics, and Auto-trol led in architectural.

EXHIBIT IV-1

DISTRIBUTION OF TURNKEY VENDORS
AMONG RESPONDENT SITES

APPLICATION / VENDOR	Mechanical	Electronics	Architectural	All Applications
Applicon	17%	20%	6%	15%
Auto-trol	14	5	46	19
Calma	9	44	6	20
Computervision	28	22	6	20
Intergraph	4	3	30	11
CADAM	20	3	4	10
Other	8	3	2	5

- Respondents that reported more than one turnkey system installed at their site or had the use of multiple vendors at a site were almost exclusively in very large companies.

- The most important reason expressed by users for selecting a turnkey system was the advantage of dealing with only one vendor for:

    - Procurement.

    - Installation.

    - Training.

    - Maintenance and support.

- One danger to users in the "single source" issue is that weaknesses in part of the total evaluation may be glossed over in favor of ease of procurement.

- However, once the system is installed, users expressed concern over being locked in to that vendor.

    - Changing or adding other vendors can be expensive and traumatic from a retraining standpoint.

    - Installing a second system from a different vendor may introduce serious incompatibilities in system operation, data bases, and files.

    - The ability to shift engineers and tasks from one system to the other to balance system loading may be severely constrained if not precluded.

- Users in medium and small companies have virtually no choice but turnkey:

- They typically do not have the resources or expertise to build a system from software packages and hardware components, much less develop their own software.

- Remote computing services offerings are perceived as being either inadequate or too costly.

- A number of computer manufacturers have announced that they will begin selling "turnkey" systems consisting of their equipment plus licensed CAD/CAM software.

    - Users must be cautious and insure that the vendors have adequate staff who are experienced in CAD/CAM systems and applications and are able to offer adequate training and support.

2. INDEPENDENT SOFTWARE

- The independent software segment is a very small part of the overall CAD/CAM market today.

- Independent software vendors typically offer only their software products and are not involved in any hardware offerings. Hardware is left up to the end user, system integrators, or OEMs.

- Most of the software products on the market are single or limited purpose packages designed for very narrow applications.

    - Structural analysis.

    - Thermal analysis.

    - Drafting.

    - Circuit analysis.

- Very few general purpose or multifunction CAD/CAM software systems are available.

  - One example of an independent software system for a variety of applications and functions is ANVIL-4000 from MCS, Inc.

  - ANVIL-4000 is available for a number of computers including Data General, Digital Equipment, IBM, Perkin-Elmer, and Prime.

- Limiting factors on the growth of the software market have been:

  - Cost of hardware on which to run the software.

  - Relatively small total CAD/CAM market.

  - Limited use of CAD/CAM beyond basic design and drafting functions.

  - Reputation and viability of software suppliers.

- A barrier to the use of independent CAD/CAM software systems is the lack of available capacity on in-house mainframes.

  - This is usually compounded by limited in-house DP staff resources for new applications installation and support.

- The use of independent software packages by respondents to the INPUT survey is shown in Exhibit IV-2.

- Virtually all of the packages were used for analysis or other narrow functions. Some of the packages listed were:

  - Mechanical:

    . MSC Nastran.

EXHIBIT IV-2

USE OF SOFTWARE PACKAGES AND RCS
TO PERFORM ANALYSIS OR PROVIDE SUPPLEMENTAL APPLICATIONS

APPLICATION	Percent Using INDEPENDENT SOFTWARE PACKAGES		Percent Using REMOTE COMPUTING SERVICES	
Mechanical		24		19
	1 Package	15	1 Vendor	14
	2 Packages	9	2 Vendors	5
Electronics		18		14
	1 Package	11	1 Vendor	10
	2 Packages	7	2 Vendors	4
Architectural		9		16
	1 Package	4.5	1 Vendor	7
	2 Packages	4.5	2 Vendors	4.5
			3 Vendors	4.5

- Swanson ANSYS.
- SDRC Supertab.
- Uniapt.

- Electronics:
  - SCI-CARDS.
  - Phoenix Data LOGCAP.
  - TEGAS.

- Architectural:
  - Nastran.
  - Sinda.
  - ADLPIPE.

- Some software and turnkey vendors have recently entered into agreements to link the independent packages and allow them to run on the turnkey system or at least accept input from it:

  - Applicon and Computervision are now compatible with and will produce NC source code for both MDSI Compact and Apt.

  - SDRC Supertab is now available on Applicon systems.

- While this cooperative integration provides a broader market for software vendors, it will probably decline after the turnkey vendors have time to develop their own packages or secure exclusive rights to outside software.

- Users who need more software capabilities than their turnkey vendors can provide should be encouraged by this trend, even if it is limited.

- As the turnkey installed base grows, more specialized software vendors will emerge to extend the range of turnkey system capabilities.

3. REMOTE COMPUTING SERVICES

- Respondents in all three application areas reported using remote computing services in conjunction with their CAD/CAM systems, as shown in Exhibit IV-2.

- Nearly all RCS mentions were for modeling or analysis. For example:

  - CDC ISPICE.

  - ISD LOGIS.

  - UCS MEDICIRCUIT.

  - MCAUTO FASTDRAW.

  - MCAUTO STRUDL.

  - UCC NASTRAN.

- Only one respondent reported using MCAUTO CADD.

- The RCS approach for computer-aided design and engineering can be very costly because of the high data rates needed to drive a remote graphics device.

- Decreased costs and increased storage and processing capabilities in remote workstations will contribute to the viability of RCS for CAD/CAM by reducing the communications intensity.

- As turnkey users become more involved in design analysis, the need for more comprehensive analytical processing will increase.

- It remains to be seen whether this need will develop slower than the growth in the computational capacity of turnkey systems or if it represents a growing market for RCS vendors.

4. HARDWARE

- A vast array of hardware applicable to CAD/CAM systems is available today, ranging from complete systems to individual components.

- The problems of product identification, selection, and integration are even greater than with software products, forcing all but the larger user companies to default to their turnkey vendors or nationally prominent suppliers.

- Some users expressed the fear that interfacing a plug compatible device purchased from another vendor to their turnkey system would worsen the already marginal level of vendor support.

C. RECENT DEVELOPMENTS

- Although the CAD/CAM industry has never been noted for being in a calm state, the past year has been an especially active one. Some of the more interesting and significant announcements and developments are summarized below.

I. TURNKEY VENDORS

- Applicon announced a solids modeler which converts a 3-D wire frame design to a solid. Conversion is performed off-line, but the solids model can then be manipulated on-line.

  - Applicon is heavily promoting the visibility of solids models with the added dimension of color output (including their color plotter).

- Applicon also signed an agreement with SDRC and is offering SDRC's SuperTab finite element modeler on their systems.

- Applicon is commiting considerable resources to improving their market position in the mechanical sector.

- Remote workstations announced by Calma, Computervision, and Intergraph will function as standalone systems (typically one to two workstations) or act as nodes in a distributed system.

- Auto-trol also announced an entry level system expandable to two stations.

- These announcements are significant in that they:

  - Lower the user entry cost to the $200,000 range, thus broadening the market.

  - Will allow users to distribute their capabilities and establish networks.

  - Narrow the gap between present top end systems and small, entry level systems.

  - Have the potential for placing a new support burden on vendors because of more systems, more sites, and less experienced users.

- McDonnell Douglas Automation (MCAUTO) is also becoming very active in CAD/CAM systems and services.

  - It is enhancing its field sales and support staffs and can be expected to upgrade and place a renewed emphasis on Unigraphics.

  - It announced Fastdraw 3 finite element modeling plus structural analysis as a packaged system on the VAX 11/780.

  - It licensed software from Applied Research of Cambridge (2-D general purpose drafting, 3-D architectural design).

- Evans and Sutherland first acquired rights to the ROMULUS geometric modeling software, then later acquired Shape Data Limited, the developer of ROMULUS. This makes E&S one of the early entrants in the emerging market for solids modeling systems.

2. NEW ENTRANTS

- A noteworthy new entrant in the mechanical applications field is Graphics Technology, founded by ex-Auto-trol people. Its base system is AD 2000 derived software running on SEL computers.

  - System size and capabilities put it in direct competition with the major turnkey vendors.

- AM Bruning signed an exclusive marketing agreement with Grafcon for their EasyDraf2 general purpose drafting system (desktop, single station). Bruning's large sales force in the engineering marketplace makes this a significant venture.

- The Bruning/Grafcon venture is another entry in the low-end or entry level marketplace.

- This market segment, occupied by companies such as Summagraphics, Redac, Holquin, Sigma Design, and Nicolet, has as many as one new vendor enter per month.

• The added choices are of definite interest to potential users, but the dynamic nature of this segment also poses some risks.

• Computer manufacturers are also rushing to get on the CAD/CAM bandwagon, usually through the licensing of software.

• DEC, Perkin-Elmer, and Prime have announced the availability of MCS's AD-2000 software (recently upgraded to Anvil-4000).

• The success of computer manufacturers in the turnkey or "packaged" systems business will depend entirely on their commitment to support: just offering the system is not enough to attract knowledgeable customers.

• Control Data and IBM are both investing heavily to go after market share in CAD/CAM.

  - CDC is offering its AD-2000-based system, supplemented with a professional services group.

  - IBM has a strong position in the mechanical sector with Lockheed's CADAM and is reported organizing for a major thrust in 1982.

  - IBM has also licensed circuit board design software from Bell Northern Research.

• The General Electric acquisition of Calma could result in a powerful combination because of GE's resources and vast remote computing services network.

  - GE/Calma is perfectly poised for the time when distributed, remote processing systems come of age.

- Schlumberger is another major CAD/CAM entrant with its acquisition of MDSI and offer for Applicon.

  - Schlumberger's resources, its earlier acquisition of Fairchild, and now its involvement in CAD/CAM represent yet another potentially major force in the market.

  - The involvement of major corporations such as CDC, GE, IBM, and Schlumberger will dramatically affect the course of the industry.

3. SERVICES AND SOFTWARE

- Lockheed broadened the capabilities of its CADAM software with the announced agreement to incorporate the ASI PRANCE printed circuit board software.

  - This will increase the market appeal of CADAM for PCB electronics users, as well as companies with both mechanical and PCB needs.

- Manufacturing and Consulting Services (MCS) announced its intention to open five remote computing centers in the next two years.

  - MCS-leased intelligent, full function or non-intelligent workstations will access the center hosts for processor-intensive calculations over the Tymshare network.

  - The software to be used is MCS's new ANVIL-4000, an enhanced system based on its earlier AD-2000 software.

  - This is a significant departure from MCS's role as a software supplier. Its ability to fund, market, and support such a venture is an issue.

- Structural Dynamics Research Corporation (SDRC) established a series of walk in design centers in the U.S. and Europe. Each center will have a CAD system

including the SDRC software for operation by the customer or the SDRC operator.

- The SDRC approach has appeal to people with overload problems, inadequate needs to justify a system, or those who want to try a system before buying.

- INPUT encountered several small CAD/CAM service operations in the course of the research, usually consisting of users selling excess time on their turnkey systems.

- At issue is the survival of this concept in the face of declining system prices and increasingly cost effective RCS offerings.

4. FOREIGN VENDORS

- Ferranti-Cetec (Scotland) acquired a 14% share in Vector General. Ferranti sells a VAX-based mechanical turnkey system in Europe.

    - A joint venture between the two could give Ferranti ready access to the U.S. market.

- Compeda (England) which sells systems for IC & PCB design, 2-D drafting, and plant design and management, has announced its intention to open sales offices in the U.S.

- Prime Computer will offer the Medusa software from Cambridge Interactive Systems for general purpose 2-D and 3-D design and drafting.

- These announcements represent an interesting turn of events since several U.S. turnkey vendors have been doing a brisk business in Europe for some time.

- Japan will acquire another U.S. presence in its CAD/CAM market through the licensing of CADAM by Lockheed to Fujitsu.

- This is an interesting relationship because Fujitsu is an IBM competitor and will sell CADAM on their IBM software compatible mainframes.

- IBM and Fujitsu have non-exclusive licenses to market CADAM.

- This could provide Fujitsu with an excellent marketing learning vehicle and a later springboard into broader markets outside of Japan.

V GOVERNMENT AND UNIVERSITY PROGRAMS

V GOVERNMENT AND UNIVERSITY PROGRAMS

A. INTRODUCTION

- Government and university efforts have long been a source of technology advancements for the private sector.

- Government programs typically consist of major programs aimed at large companies, while university efforts are more oriented toward narrow technological developments.

- There is a significant lead time before developments from either sector can be translated into products useful to medium-sized companies.

    - Most end users do not have the resources or the expertise to perform this translation into a product which is scaled down to a range of functions applicable to their needs; hence, they must rely on the systems and software vendors.

    - INPUT is concerned that this diffusion of technological developments could be slowed by the increasingly tight supply of skilled application and software development specialists.

- INPUT recommends that users closely track government and university programs applicable to their industry.

- Some of the work bearing on organization, procedures, or methodologies may be directly applicable to their needs.

- Indications of future directions in processes, techniques, and technologies can be invaluable as long-range planning considerations.

B. GOVERNMENT SPONSORED PROGRAMS

1. PROGRAM PERSPECTIVE

- The need to integrate and automate the design and manufacturing activities of U.S. industry has been magnified by declining productivity levels.

- The Federal Government perceives its role as providing seed money to spur development and application of computer technology to industry design and manufacturing activities.

- Federally funded programs are designed to accomplish two tasks:

  - Improve productivity of U.S. industry through application of computer technology.

  - Reduce Department of Defense weapon system acquisition cost through improved methodologies for design and manufacturing.

- The total amount of funding over the next five years will approach $2 billion and will be distributed over the following government agencies, as shown in Exhibit V-1.

  - Department of Defense.

  - U.S. Army.

EXHIBIT V-1

TOTAL CAD/CAM FUNDING

• Agency – Project . Application	FUNDING ($millions)	PERIOD
• NASA – IPAD	$ 50	1977-1986
• AIR FORCE – ICAM* – ICAD	200	1979-1987
• ARMY (Manufacturing Methods and Technology) – ECAM – HICADAM	200	1981-1987
(Facilities Programs) – XMITANK . T700 Turbine Engine . Cannon Production	800	1981-1987
• NAVY – Shipbuilding Program		1981-1987
. Software	80	
. Tooling	420	
• DEPARTMENT OF DEFENSE – VHSIC	300	1981-1987
TOTAL	$2,050	

*DOES NOT INCLUDE FACILITIES IMPROVEMENT FUNDING.

- U.S. Air Force.

- U.S. Navy.

- National Aeronautics and Space Administration.

- National Bureau of Standards.

2. DEPARTMENT OF DEFENSE (DOD)

- The major program being funded by the DOD is the Very High Speed Integrated Circuits (VHSIC) program. This project is an effort to counteract the declining portion of the integrated circuit (IC) market purchased by the DOD.

    - DOD purchases represented 70% of the IC market in 1965 and 7% of the market in 1980.

    - Commercial products do not meet DOD system requirements for radiation hardness and throughput.

- VHSIC is a program to leverage commercial IC research and development efforts to ensure that future products include requirements peculiar to DOD system needs.

    - Between $250 and $300 million is budgeted over the 1980-1985 period. The FY 1981 budget was $34.2 million.

    - IC dimensions will be driven to the submicron level.

    - Advanced CAD techniques will be developed to reduce cost and risk of new circuit development.

- An additional DOD funded program is the Very Large Scale Integration (VLSI) research project being conducted by the Defense Advanced Research Projects Agency (DARPA).

- Goals of this project include developing:

  - Innovative circuit architectures.

  - CAD and process simulation tools.

  - Design methodologies.

  - VLSI of one million or more gates.

- This multimillion dollar project is designed to significantly reduce design and fabrication costs through the use of network-based design methodologies, support systems, and process simulation aids.

3. UNITED STATES ARMY

- The CAD/CAM related projects being conducted by the U.S. Army are overseen by the Manufacturing Technology Advisory Group of the Department of Defense and administered through the U.S. Army Development and Readiness Command (DARCOM). Goals of this ongoing program are to:

  - Reduce costs of defense systems through integration of computer technology with manufacturing.

  - Ensure surge capacity for defense system production requirements.

  - Improve reliability of defense system products.

- Research activities are distributed among eleven separate thrust areas previously defined in the U.S. Air Force Integrated Computer Aided Manufacturing Program (ICAM). They are based on:

  - Funding of $24 million in 1981-1982 for research into manufacturing methods.

  - Funding of approximately $100 million for manufacturing facilities improvement in 1980-1982.

- An additional project is the Electronic Computer Aided Manufacturing (ECAM) program.

  - ECAM is a five-year, $68 million project.

  - Its purpose is to develop a generic manufacturing architecture for electronic equipment and systems.

    . Manufacturing systems will be developed to meet production requirements of the electronics industry in the 1990s.

    . A top-down design and bottom-up implementation and integration of manufacturing modules will be carried out.

    . Efforts will be closely coordinated with the DOD VHSIC program to ensure consistency of fabrication methods for advanced circuitry.

4. UNITED STATES AIR FORCE

- The Integrated Computer Aided Manufacturing Program (ICAM) is a multi-year program funded at $100 million through 1984. Additional phases are scheduled for 1984-1987. Goals of this project are to:

- Shorten the implementation time to incorporate compatible and standard techniques within the aerospace manufacturing industry.

- Improve aerospace industry response to DOD needs.

- Reduce defense system costs by the application of computer technology to the fabrication of defense materials.

- The procedure employed during the course of the ICAM program is as follows:

  - Define generic manufacturing as it is today.

  - Define manufacturing system requirements for the needs of the 1990s.

  - Analyze present procedures for redundancy, errors, and voids.

  - Optimize architecture for manufacturing as it will be in the future.

  - Implement and demonstrate viability of architecture at the process, cell, and center levels.

- The potential impact of the ICAM program is greatest among organizations working under contracts to produce defense weapons systems. Future government contractors may be required to upgrade existing facilities and procedures to meet performance levels associated with ICAM implementation if they are to be considered responsive.

5. UNITED STATES NAVY

- The United States Navy is embarking on a five-year, $500 million project to apply computer-aided design and manufacturing tools to the shipbuilding process. Activities include:

  - $80 million in software development.

- Extensive CAD/CAM systems acquisition activities for Naval Weapons Centers.

- Networking of CAD facilities between Weapons Centers.

6. NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

- NASA is the funding agency for the Integrated Programs for Aerospace Vehicle Design (IPAD). IPAD is a project begun in 1976 to develop systems software to be used in the manipulation of engineering data within the aerospace industry.

- Phase I is scheduled for completion during the fall of 1981 with Phases II and III proposed to further define the prototype software developed during Phase I.

- There are four major software elements within IPAD.

  - Executive software.

    - Command.

    - Control.

  - Utilities software.

    - General.

    - Graphics.

  - Data management software.

    - Define.

    - Store.

- Track.
- Retrieve.
- Update.
- Protect.

- System interface.

  - IPAD.
  - Non-IPAD.

- IPAD software is designed to augment rather than replace the operating systems of present hardware. The initial software will be supported on IBM, CDC, and DEC computers.

- The IPAD project is run in close cooperation with the ICAM project of the U.S. Air Force to ensure that the systems are compatible and future integration efforts will allow for manufacturing organizations to access and manipulate design data using the system capabilities associated with IPAD.

7. UNIVERSITY ACTIVITIES

- Most university activities within the CAD/CAM arena are funded by the U.S. government through the programs previously mentioned.

- Software and system development are the main activities being conducted by universities.

- Programs and universities involved include:

  - VHSIC.

- Stanford.
- Cornell.
- University of Southern California.
- Carnegie Mellon.

- ICAM.

  - Brigham Young University.
  - Carnegie Mellon.
  - Georgia Institute of Technology.
  - Massachusetts Institute of Technology (MIT).
  - North Carolina State University.
  - Notre Dame.
  - Ohio State University.
  - Pennsylvania State.
  - Purdue.
  - Texas A&M.
  - University of California.
  - Virginia Institute of Technology.

- Continued involvement of the academic community in government funded programs reflects the coalition-based strategy to include all interested parties in the development phase to ensure and facilitate the technology transfer upon completion of the projects.

C. UNIVERSITY PROGRAMS

I. JAPAN

- Several activities are conducted outside the umbrella of government funding.

  - One such activity is the Solids Modeler developed at Hokkaido University in Japan during the 1970s. This system, called the Technical Information Processing System (TIPS-I), uses the constructive solid geometry concept and has nine primitives, including objects, with user-defined free-form surfaces.

  - The system is presently being evaluated at Cornell University under funding by the National Science Foundation and Computer-Aided Manufacturing-International (CAMI).

  - Initial results indicate that the TIPS-I solid modeler is an effective tool to augment the transfer of design data to a manufacturing context. As a solids modeler, it is able to uniquely define an object in a manner more readily applicable to manufacture by numerically controlled devices.

- While the performance of the TIPS-I system has been favorably reviewed, several criticisms have also surfaced.

- It has been shown that TIPS-I is unable to distinguish between complex and simple shapes and, as such, treats all shapes as complex. This causes TIPS-I to be artificially slow in response time.

- TIPS-I does not have a boundary representation of the object. As a consequence, it displays the perspective view in meshes with hidden lines removed. Contingent upon how the meshes are selected, some edges might be lost in the representation of the object at the workstation.

- Convair Corporation uses TIPS-I as a numerical control verification device but not as a design aid due to its lack of technical sophistication.

2. ENGLAND

- The results of university research in England have been the source for several commercial products.

  - Compeda, which is a wholly-owned subsidiary of the National Research and Development Corporation, centers its activities around the commercialization of software developed within British universities.

  - Its GAELIC software package for use in PCB and IC design was developed at Edinburgh University and then modified by Compeda before it marketed the product.

  - The Plant Design and Management System (PDMS) was developed, in part, by the Computer-Aided Design Centre which is an agency funded by the British Department of Industry to modify university developed software, as well as create software for use by British industry and for export.

- PDMS is a design aid for 3-D design and layout of process plants. Recent U.S. installations include a multi-site placement in the C.E. Lummus subsidiary of Combustion Engineering.

- University Applied Research at Cambridge has resulted in the spinoff of two separate commercial software vendors; Applied Research of Cambridge (ARC) and Shape Data. Both carried forth the work begun at Cambridge when the university became unwilling to provide continuing support.

  - Shape Data has developed a solids modeler called Romulus using as a framework the Cambridge developed BUILD system which was an experimental rather than a commercial product.

    - Romulus was earlier available in the U.S. through a licensing arrangement with Evans and Sutherland.

    - Evans and Sutherland, apparently convinced of the commercial potential of Romulus, recently acquired Shape Data Ltd.

  - ARC was also established as a spinoff of the original CAD/CAM work at Cambridge. ARC presently develops and modifies other university developed software for marketing.

    - ARC has recently announced an exclusive licensing arrangement with MCAUTO to market their 2-D General Drafting System (GDS) software and their 3-D Building Design Software (BDS) for the architectural industry. These packages are designed to operate on either VAX 11/780 or Prime 150-750 computers.

3. UNITED STATES

- In the United States, the commercialization of university developed products has been less common. One product which has been made available is the Parts Assembly and Description Language (PADL) developed by the University

of Rochester under funding by the National Science Foundation. PADL is in the public domain.

- PADL is a geometric modeler based on primitives around which a mechanical design system could be developed.

- The GMSOLID solid geometric modeler presently under development at General Motors is said to be developed and built around a few key concepts and algorithms derived from PADL-1. The GMSOLID system was scheduled for on-line service within GM during 1981.

- The PADL-2 system which is an extension and improvement of the original PADL-1 is being developed at the University of Rochester.

  - PADL-2 uses both constructive and bounded geometry.

  - Availability of PADL-2 is expected during 1982. Commercially based systems using PADL-2 concepts will arrive on the scene shortly thereafter.

- It should be noted that the apparent lag in university-based research in the U.S. can be traced to the cross-discipline nature of solids modeling problems.

  - Solids modeling is a cross between graphics, mechanical and electrical engineering, computer science, and mathematics.

- Typically, research is conducted on a departmental basis in the U.S. The multidisciplinary nature of CAD/CAM does not lend itself to being addressed on a strictly departmental basis.

  - An exception to this will be in specialized applications within a discipline, such as the software being developed by the Architectural Machine Group of the School of Architecture at MIT.

- A partial list of U.S. universities considered to be in the forefront of CAD/CAM development activities includes the following:

  - MIT.

  - Stanford.

  - Harvard.

  - Michigan State University.

  - Carnegie Mellon.

  - University of Rochester.

  - Rensselaer Polytechnic Institute.

  - University of Southern California.

  - Purdue.

  - Virginia Institute of Technology.

- Even these universities must operate under continuingly more stringent budget constraints and their degree of participation could be curtailed as evidenced by the recent cutbacks at the Harvard University Graphics Laboratory.

- Additional limitations on university developed products is a function of the ever increasing entrepreneurial opportunities for individuals with CAD/CAM expertise external to the university environment.

VI FUTURE DIRECTIONS

VI FUTURE DIRECTIONS

A. INTRODUCTION

- Any discussion of the future involves some degree of speculation. In the case of the CAD/CAM industry, there is a high degree of speculation due to rapid advances in technology and market acceptance.

- Interactive graphics CAD systems have been available for over 10 years. System architecture and technology remained fairly constant until the late 1970s when processor and display technology began to accelerate.

- Rapid advances in semiconductor technology have fueled the growth in the CAD/CAM market by making more system capabilities available at a lower cost. This lower cost per function (or more functions for the same cost) has produced a number of effects:

  - Smaller systems now have sufficient capabilities to attract users from the broader market segment of mid to small-size companies.

  - Increased product flexibility and lower development costs have encouraged a rapid increase in the number of vendors, mostly at the device or small system level.

- The rapidly expanding market is attracting large system vendors who can leverage their experience in technology and systems development.

- The older turnkey system vendors are benefitting from the increased market potential but are being pulled from their traditional product niches by competitive and user pressures.

- The revolution in microelectronics is expected to continue at its present pace (or even faster). While there is a high confidence level in predictions concerning future systems architectures and product capabilities, the rate of change in electronics could alter the timing of the projections.

B. SYSTEM ARCHITECTURES

- The predominant system architecture is still the standalone, dedicated proces sor with hard-wired displays, but this is changing rapidly.

- A strong driving force is the second generation of CAD system users who are demanding more processing capabilities for design analysis, additional applications, interconnection between CAD systems as well as CAD-to-mainframes, and the ability to locate workstations remotely from the system processor.

- System vendors have been struggling with techniques to relieve the system processor from burdens imposed by non-intelligent graphics displays. Low cost integrated circuit memories and microprocessors now make it economical and technically feasible to distribute a large part of the graphics functions to the workstations.

- Intelligent displays are becoming available with more memory capacity and almost as much processing capacity as was available on many turnkey system processors less than four years ago.

- Technological developments are rapidly removing the system-imposed limitations on CAD/CAM. The processing and memory for graphics functions, computation, data management, and communications no longer have to reside in a central processor, but can be distributed throughout the system.

- Exhibit VI-1 is a simplified example of a functionally distributed system at the macro level. Some of the individual systems will also contain special or distributed function components.

- Some of the conventional descriptions begin to blur when discussing the new systems. Until recently, a turnkey system was minicomputer-based. The distinction between turnkey system processors and mainframes was clear. Now, 32-bit processors are being used in graphics systems that have greater memory and processor capacity than many of the central data processing mainframes still in use.

- It is projected that a 32-bit microprocessor with the capability of a Digital Equipment Company VAX 11/780 will be available with one megabyte of memory for $20,000 to $30,000 by 1986.

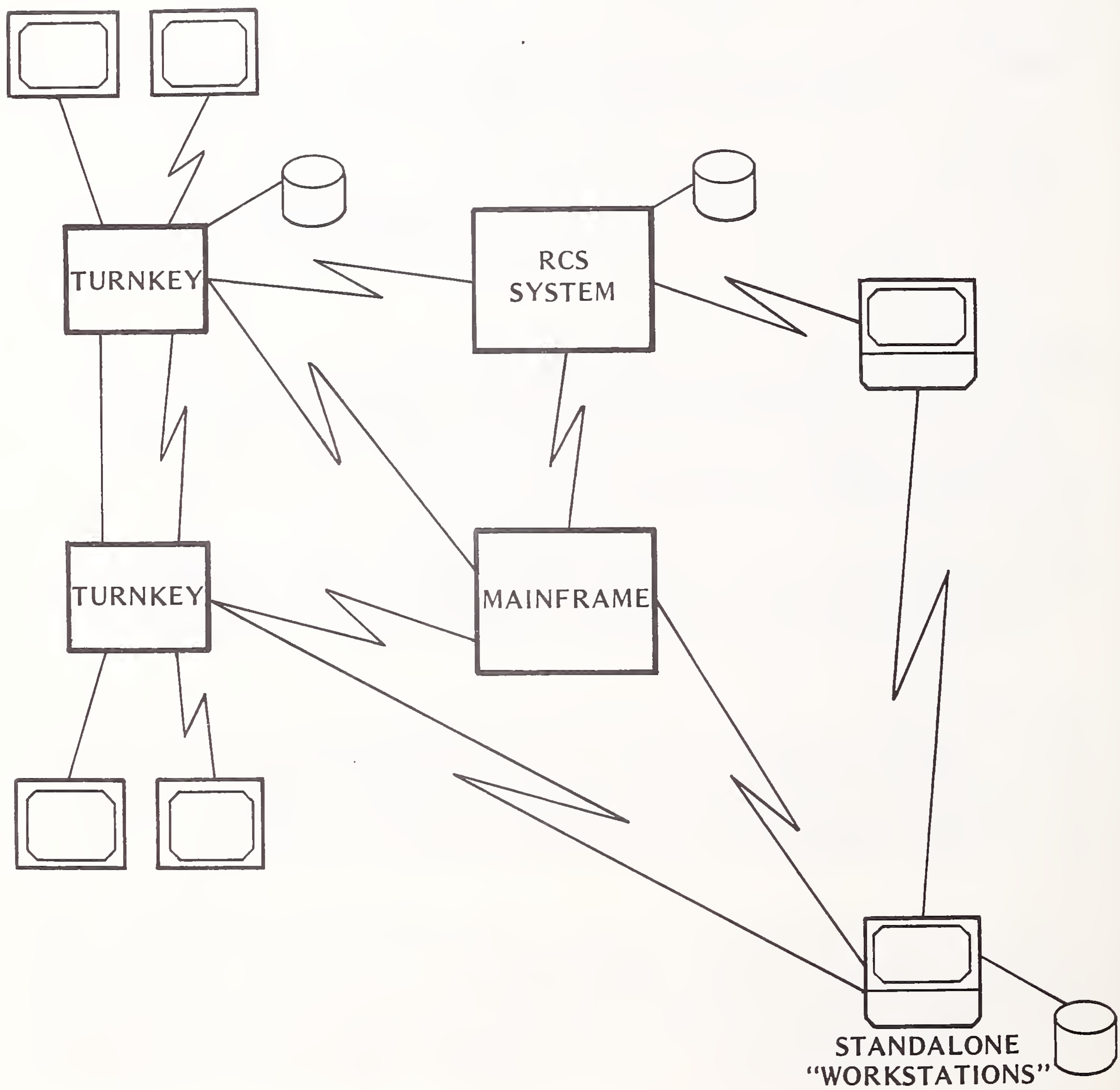
    - Even if this level is not reached by 1986, the technology coming on the market is sufficient to enable a significant evolution in system architecture over that time.

    - Systems and devices based on 16-bit microprocessors are already on the market. These processors (such as the Motorola 68000) are capable of supporting multiple processors and megabytes of memory.

- The cost and technical barriers to system and functional distribution will disappear rapidly in the early 1980s, resulting in a much wider range of options for vendors as well as users. However, this flexibility will also raise some significant new problems: both problems and opportunities are discussed below.

EXHIBIT VI-1

FUNCTIONALLY DISTRIBUTED ARCHITECTURE
(SYSTEM LEVEL)



C. FUTURE DIRECTIONS

1. TURNKEY SYSTEMS (MULTIPLE STATIONS)

a. System Processors

- The central or system processor of turnkey systems is realizing an effective capacity gain for two reasons:

  - Larger, 32-bit processors have become cost-effective for use in mid-range systems.

  - Formerly centralized functions are being distributed to the work-stations.

- Thirty-two bit processors will be the norm by 1986 because of their higher accuracy, increased throughput, and greater memory range.

- Continued functional distribution will allow the system processor to become more devoted to computations and data management.

- The requirement for data communications will increase sharply over the next five years as stations become distributed and intersystem linkages develop, but this function will also be handled by a distributed processor.

- Turnkey system vendors have been developing larger systems for some time, but have recently been forced in the other direction by competitive and market pressures. Most of the major turnkey vendors announced limited configuration systems in 1981 to allow them to reach further down into the market. This gives them a much broader potential market as well as some defense against the under $100,000 systems. It also has the potential for straining their already scarce resources.

- The larger turnkey system vendors will offer a continuous spectrum of products by the mid-1980s which will range from low cost, standalone workstations to large systems with over 25 workstations, both local and remote.

b. Software

- The vendors interviewed by INPUT showed wide differences in opinions on the direction vendors would take in developing software in the future.

  - Most felt that independent software vendors would play an important role due to resource limitations for development and support and for highly specialized applications.

  - Several major vendors reported that they were planning on developing an extensive range of products for their systems and saw no need for other software sources.

- It is doubtful that turnkey vendors will be able to afford the resources necessary to develop and support a wide range of applications for multiple industries. The more likely scenario is that they will offer a range of applications, but they will be acquired from various sources such as major customers or independent software firms.

- Vendors must look to software products to maintain revenues and profits as hardware declines in price. The 1980s will see a reversal of the past situation where software could be heavily discounted to ensure the hardware order.

- The importance of software revenues will extend the present trend of vendors offering an integrated set of applications software. It is a self-defeating strategy at the present time to put more applications on a system that is already loaded by the graphics processing, but it will become more viable as functions are distributed to more intelligent workstations.

- Systems will require extensive software additions and modifications to allow them to operate in the distributed environment of the mid to late 1980s. CAD systems will become too valuable to a customer's operation to allow them to continue in their present standalone mode. Vendors will be forced to direct their efforts toward:

  - Networking communications and control - networking with a mix of modes such as vendor supplied as well as other manufacturers' stations, other systems including CAD and mainframes, various concurrent speeds and protocols, non-intelligent terminals and peripherals, and specialized devices such as shop floor data collection terminals or direct numerical control processors.

  - File and data interchange - pre and post processors for the interchange of files with other systems; integrated data base management systems to accommodate a data structure for ease of access; organization and control of distributed data files and interface to other data bases and systems; data formatters and handlers to interface to analysis programs and other special applications.

  - Applications flexibility - varying customer requirements will require more flexible applications (menu or parameter driven) with extensive user-code facilities and exits.

c. Support

- Reduced hardware costs, and hence profits, will necessitate changes in support methods, but the improved hardware technology should enable the overall support situation to improve.

- The trend toward self-test and diagnostic capabilities will continue and extend down to the device level. Logging and reporting software will simplify fault identification and diagnosis.

- The use of redundant circuitry will increase and significantly improve reliability.

- Greater use will be made of remote diagnostics for both hardware and software. Many systems have basic capabilities for remote access, but they must be expanded to allow true on-line performance monitoring and diagnostics.

- Remote, on-line access methods for software maintenance and updates will become available as adjuncts to telephone support of operational problems.

- The operation and analysis of more general diagnostics for software and hardware will be simplified so that user personnel will be able to perform first-level diagnoses and system integrity verifications.

d. Workstations

- Continuing cost decreases in integrated circuit memories will allow raster displays to increase in resolution. One thousand line monochromatic displays are reaching the market now while 2,000 line resolution (2,000 by 2,000 picture elements or pixels) are projected by 1986. Some vendors are projecting 4,000 line monochromatic displays by 1990.

- Expanded display memories will also broaden the gray and color scales of raster displays. A greater range of shading or colors, when combined with finer resolution will remove most of the user objections to raster displays, making them the most prevalent display type in the 1980s.

- Color displays will be more widely accepted as cost declines, resolution improves, and user experience increases. One-thousand-line color displays will be widely available by 1985.

- Some vendors are forecasting the availability of thin film plasma or liquid crystal displays in the late 1980s.

- Advances in processor technology will allow more intelligence to reside at the workstation. Workstations are rapidly becoming full function systems and will include, by 1985, all of the drafting, design and graphics functions offered by today's systems.

- Although there will be a full range of workstations and systems available by 1985, from standalone limited function workstation/systems to full-function multiple-display systems, the flexibility of interconnecting them may be limited by vendor software and support.

2. SMALL SYSTEMS

- Small systems are defined here as single station systems with limited to full CAD functions. While they are technically turnkey systems (sold and installed by a single vendor as an integrated hardware/software system), they are becoming a factor in the market and merit a separate discussion.

- Small systems typically serve the low-end market segment of small companies or very narrow market segments for highly specialized applications or both.

- This market is very dynamic and will continue that way for several more years.

- The low-end market is now the domain of small companies selling systems in the $60,000 to $80,000 range. The improving price/performance ratio of processors and workstations will allow major vendors to down-size their products with minimal expenditures by effectively using their existing software and begin competing for small users.

- The larger vendors will be able to leverage their more extensive marketing resources, but the small systems market has very different characteristics from their traditional market. These include different buying patterns, less prospect visibility, higher percentage cost of sales, and less sophistication, which will dilute their marketing and support resources.

- The small system vendors will face some of the same problems as the larger system vendors:

  - User and competitive pressures will force them to develop and support broader applications.

  - Increased customer experience and utilization will create demands for networking and structured data capabilities.

- One small system vendor stated "Sharing a processor made sense in the recent past, but it doesn't now. Processors and memory are so cost effective that vendors can and should be putting all functions at the work station and only sharing through communications those functions that aren't economical at the station with some level of host system, such as large analyses or data bases. The overall system is complicated and made more expensive by having to manage multiple users, so why do it if you don't have to?"

- The small system market should stratify by the mid-1980s with the smaller vendors focusing on very narrow segments with highly specialized applications. The larger vendors will be more successful with small users who have more general applications and a need for upward compatability and growth.

3. REMOTE COMPUTING SERVICES

- Remote computing services (RCS) have not been viable in CAD because of the high data transmission requirements of graphics terminals. This situation is changing rapidly due to the increasing intelligence of workstations and small systems.

- Even though data communications costs will continue to increase in the 1980s, the level of data transfers between the CAD station and the RCS system will drop drastically.

- RCS vendors will become involved in CAD in a number of ways:

- User site hardware services (USHS) incorporate a system or station with extensive CAD capabilities which is placed at the user's site, along with the necessary software and hardware to facilitate connection and processing with the central systems.

- User convenient interfaces to turnkey systems simplify access to data bases or large scale analysis programs.

- RCS networks can function as either a distributed network for companies who do not have their own or an extension to limited company networks.

- Develop proprietary applications and data bases and enhancements to existing RCS applications.

- Offer a wider array of applications than are available from turnkey system vendors.

- RCS will also offer first-time users an opportunity to get started in CAD/CAM or evaluate its feasibility without extensive capital commitments.

4. INDEPENDENT SOFTWARE

- While independent software packages will never capture a major share of the total CAD/CAM market, they will play an important role.

- Software vendors will be a major source of applications packages for system vendors.

    - The rate of change in system flexibility and capabilities, coupled with new applications demands, will strain most system vendors resources.

    - As user experience and sophistication increases, they will demand more extensive applications. It will not be feasible for some system vendors

to attempt to acquire the specialized skills to develop this software, especially if they are serving multiple industries.

- One vendor characterized the present turnkey systems as "do-all systems," and felt that the growing user sophistication would force companies to become applications oriented to survive. Since the change from "do-all" software to a strong applications focus would saturate most of the present vendors in his opinion, it would open the market to software specialty companies.

- The growth of CAD/CAM integration will also boost independent software sales. The number of potential system and application interface possibilities will be greater than system vendors will be able to, or want to, address.

5. INTEGRATION

- The mainframe shown in Exhibit VI-1 is the repository today for the corporate data bases and applications. Integrating the CAD/CAM systems and data is the real challenge of the 1980s for both users and vendors.

- User respondents rated the status of integration at 3.6 in 1981 and 6.5 in 1986; a sampling of vendors yielded surprisingly similar responses of 2.5 and 6.9 (on a scale of 1 to 10 where 1 is not integrated and 10 is completely integrated).

- Integration is principally a data management and transfer issue. Data from the CAD function is a vital element in the manufacturing and management planning and control processes. The close integration of the functions of engineering, manufacturing, and management is difficult to achieve on a broad scale due to unique requirements and multiple formats and standards.

- Integration will take place on three levels:

  - Device - the interconnection of devices is well defined through standard interfaces and protocols. This area will present no significant problems.

- Direct data transfer - the direct coupling of an application to the CAD data files. Data is transferred to the application for processing with no manipulation or reorganization of the data structure. The data is organized or formatted uniquely for each application. The application may reside on the CAD system or on a separate processor. Examples are numerical control machine data or source program output and finite element mesh data transfer to analysis programs.

- Indirect data transfer - the indirect coupling of applications through a structured, organized data base for centralized access by multiple applications. The data will usually be reorganized and merged into a higher level structure for ease of access, update, and manipulation.

- Direct data integration is taking place on a limited scale for numerical control, simulation, analysis, and bills of materials and will increase in the future as vendors increase their repertoire of applications.

- The problem with the direct approach is the number of unique interfaces required when multiple vendor systems are linked to both internal and external applications. IGES, GKS or similar data exchange standards will help reduce the problem by requiring only interfaces to a standard data structure.

- A sampling of 12 vendor interviews showed estimates of from one to ten years for data standards to be established. Most felt it would be IGES or a variant of IGES. Interestingly, one vendor respondent saw no need for standards.

- This sampling of vendors ranked organizational conflicts as the greatest barrier to integration, followed closely by lack of standards. The other factors in their rank order were incompatibility of components, cost, unproven benefits, complexity, and security.

- Data exchange standards development is accelerating, and adequate vendor implementations will be completed in several years. This will resolve a number of the direct data integration problems, but users will still be required

to deal with some standards dialect problems as well as the interface to unique or unsupported applications.

- All vendors reported a high requirement for integrating CAD and CAM data files by 1986. Most vendors listed data base management systems as the major new software development in 1986.

- Most CAD systems today lack adequate data base management capabilities to allow them to effectively organize and process data at a level required by an integrated corporate data base. CAD file systems are designed for rapid access rather than flexible and highly structured access schemes to compatibly link them into higher level schemes.

- Since the vendors recognize this as a problem, they should be able to provide adequate data base management systems by the mid 1980s. However, the user problems will not be solved just by the availability of CAD system DBMS since they will be responsible for defining the overall corporate data structure.

- The corporate-level integration problem may be relieved to a great extent in the mid to late 1980s by back end data base processors or intelligent back end systems (IBES). These are special purpose processors which fit between the file system and the mainframes and system processors. This is another example of functional distribution which will relieve the attached system processors of the processing burden associated with data base management.

VII MANAGEMENT CONSIDERATIONS

A. PURPOSE

- The purpose of this chapter is to consolidate the issues important to managers who are involved with or impacted by CAD/CAM systems and present them in such a way as to provide additional insight into the problem areas.

- INPUT does not presume to have all the answers to CAD/CAM management issues, but rather hopes to be able to provide a new perspective on some of the major areas of concern.

- The INPUT research did not directly explore management problems or concerns, but they became clear from the comments of respondents and their ranking of factors that are involved with the management process (such as system justification and selection).

B. ORGANIZATIONAL ISSUES

- CAD/CAM systems have the potential for forcing some far reaching organizational changes as they become more intensively used and more widely integrated with other company functions which are not now closely tied into the design process.

- Respondents tended to take a mixed view of the impact of integrating engineering and manufacturing data bases on organizational responsibilities in design engineering, production planning and control, factory operations, and traditional data processing functions.

- Many saw little or no change in organizational responsibilities, but INPUT feels that this is a very short-sighted perspective, perhaps resulting from the short time respondents have been involved with CAD/CAM.

- A number of respondents felt that the use of CAD/CAM would result in, or indeed force, better communications between engineering and manufacturing. No matter what the result, communications must be improved and maintained between engineering and other key corporate functions such as manufacturing, data processing, and finance, if the benefits of CAD/CAM are to be realized.

- CAD/CAM managers have the responsibility for involving other organizations in planning activities as well as providing them with information on the progress of CAD/CAM activities.

- Early involvement will help secure the active participation of others and allow CAD/CAM managers to identify opportunities for, as well as objections and obstructions to, broader use of their systems.

- CAD/CAM systems have a proven potential for changing the way a company operates, yet many companies treat it as a localized, engineering department function.

- INPUT recommends that all companies using CAD/CAM systems establish a corporate entity responsible for planning, coordinating, and overseeing all CAD/CAM activities for the following reasons:

  - Organizational barriers can be more easily overcome.

- Individual organization's plans can be synchronized with corporate goals and objectives.

- Systems compatibility can be ensured.

- Information and experiences from various organizations can be more readily collected and disseminated.

- A broader perspective can be maintained, thus increasing the chances of identifying opportunities for transporting system capabilities outside the immediate areas of use.

- This corporate entity must take an active role in CAD/CAM activities and not just act as an overview body: CAD/CAM has too much potential to allow its direction to be set wholly by subordinate organizations.

- The data processing organization has the potential for playing a key role in future CAD/CAM activities.

  - It usually has a strong corporate presence and is looked to by management for its advice, and often sign-off, on all matters relating to computer equipment and applications.

  - It has expertise in systems, applications, networking, and data bases, all of which are key to CAD/CAM integration.

- CAD/CAM managers should establish rapport and a close working relationhip with the data processing organization.

  - As CAD/CAM systems and applications grow beyond the standalone phase, data processing can provide invaluable guidance in planning for networking and integration issues.

- It can provide input into the establishment of procedures and methods for system and data security, utilization measurement, scheduling, and other systems management issues.

- Its experience in system evaluation and selection can be applied in some cases to the CAD/CAM area.

- The data processing organization may offer to become directly involved in CAD/CAM support or implementation, but CAD/CAM managers should use caution because of the extensive backlog in most data processing shops.

- Managers should keep the data processing organization in an advisory and support role, retaining as much authority as possible solely within the CAD/CAM organization.

C. SYSTEM EVALUATION AND SELECTION

- System selection is a confusing and complex area to many managers and one which was apparently not given much weight by a number of the respondents.

- Many respondents felt that most CAD/CAM vendors and systems were about the same. In fact, there are differences and even the subtle ones can be significant in such a critical application.

- There is probably more differentiation among vendors than their products. The vendor analysis phase of system selection is a critical one. Because of the rapid growth of the industry and the limited resources of most vendors, there are significant regional differences which must be taken into account by potential buyers.

- Managers must maintain a broad perspective and avoid limiting their systems evaluation to strictly technological issues. Some important factors, such as

vendor capabilities, are not directly measurable and hence are sometimes overlooked or downplayed by technically oriented people.

- The immediate application need is important, but anticipated future requirements must be taken into consideration in the evaluation process.

- A balanced team is important in developing a thorough and objective set of evaluation criteria. Engineering should not attempt to perform the entire task alone, but should seek the assistance of other groups such as manufacturing, data processing, finance, and legal.

- Criteria weights must be objectively set, again with inputs from outside groups.

- An important first step in the evaluation process is the collection of information on systems, products, technology, and techniques. Information collection should be an on-going process to facilitate system add-ons and keep key people current. Some sources of information are:

  - Vendors, which are cooperative, but not always the most objective source.

  - Trade or association shows such as National Computer Graphics Association, International Machine Tool Show, and Society of Manufacturing Engineers.

  - Trade magazines such as <u>IEEE Computer</u>, <u>IEEE Computer Graphics and Applications</u>, <u>Electronics</u>, <u>Computer Graphics World</u>, etc.

  - Newsletters such as <u>The Anderson Report</u>, <u>The Harvard Newsletter on Computer Graphics</u>, etc.

  - Professional societies.

- Vendor user groups.

- Peers in other companies.

1. EVALUATION CONSIDERATIONS

- Exhibits VII-1 through VII-6 list a number of topics for managers to consider when evaluating CAD/CAM systems.

- These lists are not intended to be all-inclusive, but rather to supplement those prepared by users. The lists generally address only those topics of concern from a manager's viewpoint and do not cover detailed technical topics.

- Many of the topics were included as a result of respondents' comments; either from direct quotes, or as inferences drawn from discussions of problems.

- Development of an evaluation checklist should be a continuing management process. Many factors will be added or modified after the system has been selected and installed, giving the checklist added value in subsequent evaluations.

2. VENDOR CONSIDERATIONS

- The vendor's stability is a matter of concern to a potential customer because of the long-term nature of the CAD/CAM commitment. Another critical area is the vendor's experience in the application for which one will be using the system. They may have the resources to remain in business, but they may not be able to effectively support an application.

- Another consideration listed in Exhibit VII-1 is the source of the products offered by the vendor. Offering products as an OEM (original equipment manufacturer) reseller is not in itself a negative factor. It can be a wise decision for a vendor, but it will only be of benefit to the customer if the

EXHIBIT VII-1

SYSTEM EVALUATION— VENDOR CONSIDERATIONS

- Experience/Stability
  - Years in Business
  - Senior Staff Backgrounds
  - Financial
    - Past 3 Years Performance
    - Annual Report
    - SEC 10K Report
  - Installed Base
    - Number of Systems
    - Geographic Concentration
    - Systems by Application and Time
  - Applications Experience
    - Length of Time in Field
    - Staff (Development and Support)
    - Number of Systems
- References
  - Customer
  - Business
- Product Sources
  - Hardware/Software
    - Internally Developed/OEM
  - Support
    - Directly by Vendor
    - Arranged by Vendor
    - Arranged by User With Originator
- Contractual
  - Flexibility
  - Warranties
    - Software/Hardware
    - Support Response
    - System Availability
    - System Performance
  - Specifications
    - Product Features/Capabilities
    - Product Performance
    - System Acceptance
  - Installation/Acceptance
    - Schedule
    - Responsibilities
    - Specifications
  - Delivery Commitments
  - Damages/Liabilities
  - Cancellation Provisions
  - Payment Terms
  - Upgrade Provisions
    - Impact of Adding Other Vendors' Software/Hardware

EXHIBIT VII-2

SYSTEM EVALUATION—
SUPPORT CONSIDERATIONS

- Vendor Profile
  - Support Staff
    - National/Regional/Local
    - Specialists/Generalists
    - Local Capabilities
      - Location
      - Number
      - Specialties
      - Experience Levels (with Company and in Area of Specialty)
  - Response System
    - Regional and Headquarters Back-up
    - Telephone Support Center
    - Response Performance
      - Guaranteed
      - Actual
- Training
  - General
    - Basic and Advanced
    - Frequency
    - Duration
    - Location
    - Facilities
    - Vendor Staff Experience
  - Management Training
  - Software Training
    - Systems and Applications
    - Use and Programming
  - Operations Training
    - Workstation
    - Central System
- Software Updates and Releases
  - Timing/Frequency
  - Costs
  - Media
  - Installation Responsibility
  - Documentation
  - Test Cases
  - Failure Reporting System
- Installation Support
  - Site Planning
  - Site Preparation
  - Acceptance Testing
    - Hardware/Software
    - User or Vendor Supplied Tests
    - Test Criteria/Specifications
- Hardware Support
  - Preventive and Scheduled Maintenance
    - Schedule
    - Responsibilities (User and Vendor)
  - Unscheduled Maintenance
    - Guaranteed Response
  - Spares Stocking (Level and Location)
- Users Group
  - Size (National and Local)
  - Meeting Frequency
  - Effectiveness

VII MANAGEMENT CONSIDERATIONS

EXHIBIT VII-3

SYSTEM EVALUATION–
SYSTEM MANAGEMENT CONSIDERATIONS

- Utilization Measurement/Reporting
  - Activity Logging
    - Central System
    - Workstations
    - Individuals
    - Project and Contract
  - Reporting
    - Utilization Accounting
    - Report Writer
    - Accounting Package Hooks
- Security
  - System Access/Log-on
  - File Access Protection
  - File Back-up/Save
  - File Recovery
- System Control
  - Workstation/Terminal Control
  - System Partition Control
  - System Activity/Performance Monitoring
  - Error Logging and Reporting
  - System Recovery/Restart
  - File Control (Purge, Restore, etc.)
  - Operator Messages (Clarity, Extent)
- User Maintenance
  - P. M. Requirements
  - Diagnostic Capabilities

EXHIBIT VII-4

SYSTEM EVALUATION—
SOFTWARE CONSIDERATIONS

- General
  - Arithmetic Accuracy
  - Data Base Accuracy
  - Upward Compatibility
    - System Software
    - Graphics Functions
    - Applications
  - Concurrent Operations Support (Foreground/Background; On-line, Batch, Communications)
  - Operating System
    - Developer (Vendor or OEM)
    - Version Level
    - Level of Support
    - Checkpoint/Restart Features
- User Aids
  - Higher Level Languages
    - Type (Fortran, Pascal, etc.)
    - Industry Standard Compliance
    - Machine Independence
  - User Programmable Graphics Functions
  - User Access to Graphics Data Base
  - Macro Capabilities
  - System Utilities (Media Conversion, File Save/Restore, etc.)
  - Documentation, Training and Support
- File and Data Management
  - Data Base Management
    - Type/Organization
    - Graphical and Attribute Data
    - Report Writer Facilities
    - Inquiry Capabilities
  - File Maintenance
    - Save/Restore
    - Update/Merge
  - Read/Write/Delete Protection
  - File Interchange Pre and Postprocessors
    - IGES
    - GKS
    - Other System-to-system
- Applications
  - Documentation/Support
  - Source Code Availability
  - User Code Exits ("Hooks")
- Interface to External Systems
  - Communications Protocol Support
  - Data Formatters/Handlers
  - System Linkage ("Handshaking")

EXHIBIT VII-

SYSTEM EVALUATION—

HARDWARE CONSIDERATIONS

- System Processor
  - Upward Compatibility
  - Memory
    - Size/Performance Relationship
    - Word Length
  - Expansion
    - Memory and I/O Channels
    - Cost
    - Ease of Installation
  - Communication Interfaces
    - Types
    - Speeds
    - Protocols
- Peripherals
  - Disk Storage
    - Capacity
    - Storage Sizing
      - User
      - System
    - Speed
  - Magnetic Tape
    - Speed
    - Formats
    - Compatibility with Data Processing
  - Plotter Interfaces
  - Optional Peripherals (Digitizers, Line Printers, etc.)
  - Device Handler/Driver Support
  - Plug Compatible Peripheral Limitations
- Maintenance
  - Repair Data
    - Mean Time Between Failures
    - Mean Time to Respond
    - Mean Time to Repair
  - Preventive Maintenance
    - Schedule
    - Training
    - Responsibilities
  - Sc[illegible]uled Maintenance
    - [illegible]quency
    - [illegible]ation
    - [illegible]ctivities

EXHIBIT VII-6

SYSTEM EVALUATION – USER INTERFACE CONSIDERATIONS

- Human Factors
  - Single/Dual Display
  - Workstation Layout
    - Controls Placement
    - Ease of Use
    - Cursor Control Devices
  - Environmental
    - Lighting
    - Temperature/Humidity
    - Special Requirements
- Station Commands
  - Range, Type and Flexibility
  - Input Method
    - Menu/Definable
    - Keyboard/Light Pen/Cursor
  - Documentation
  - User Definable
  - "Help" Capabilities
  - Error Messages
    - Extent
    - Clarity
- Workstation Intelligence
  - Functions (Pan, Zoom, Rotate, etc.)
  - Expandibility
    - Memory
    - Functions
  - Degree of System Processor Independence
  - Function Speeds
  - Local/Remote Capabilities
- Display Features
  - Technology (Raster, Vector, Storage)
  - Resolution/ Number of Vectors
  - Brightness/Contrast
  - Size
  - Color/Gray Levels

vendor has the industry and applications experience as well as the resources to effectively package, enhance, and support the products.

- The contractual items listed are those of the greatest concern to the CAD/CAM manager since they deal with the performance of the vendor and the products. Legal or contracts administration departments may not be as sensitive to performance issues as system managers, so they should be certain that they are protected and have recourse in the event of a performance default.

3. SUPPORT

- One of the key support considerations listed in Exhibit VII-2 is the local support staff and its back-up organization. Numerous respondents complained about their local support and apparently had not closely investigated this issue in the evaluation process.

- A large, national support organization is meaningless to a user if he does not have adequate support on the local level. National hot-lines or telephone support centers are effective for minor problems, but cannot substitute for on-site support of major problems.

- Software releases and response to bug reports were cited as a serious problem by numerous respondents. One of the best sources of information on how well a prospective vendor performs in software maintenance is other customers in the same area.

- Since support performance can be so highly localized, it is recommended that contact be made with as many customers as possible to factor their experiences into the evaluation criteria weighting.

4. SYSTEM MANAGEMENT

- Exhibit VII-3 lists some of the more important factors which will enable a manager to measure and control the performance of his system.

- Responses to the INPUT study indicated that many installations were not performing any extensive system utilization measurements. Some respondents complained of inadequate vendor-provided system accounting packages.

- Utilization measurement and system performance monitoring are important management tools to ensure that the system is meeting its performance goals. They also provide valuable planning data for new applications and system upgrades.

- System tuning or performance optimization is essential to realizing the maximum productivity gain of the system users. The complexity of concurrent system operations makes system management capabilities a mandatory vendor offering.

- System security and control features are also important because they allow a manager to maintain the integrity of the system, which has a direct bearing on productivity and user confidence.

5. SOFTWARE

- One of the key considerations in the software area is the ability to tie the system into other systems and applications, as shown in Exhibit VII-4.

- No vendor offering can be expected to perfectly fit a customer's needs. It is important to investigate the ease with which new applications, enhancements or modifications can be tied into the vendor software.

- Ignoring the flexibility, accessibility, and user aids issues could result in major problems when the integration of CAM functions begins.

- An integration plan or need also raises the importance of a thorough data management evaluation. Data base management is generally weak in CAD systems. Most systems have adequate data management capabilities for a

standalone environment, but lack the more sophisticated capabilities necessary for CAM integration or networking into a mainframe-based data base.

- If data base networking is anticipated, managers should seek the guidance of data processing in establishing the data management evaluation criteria.

6. HARDWARE

- The hardware considerations in Exhibit VII-5 address two basic areas: system sizing (the determination of the hardware complement necessary to support anticipated utilization) and maintenance.

- System sizing is important for two reasons:

    - Determining the optimum configuration for the initial load/response requirements.

    - Ensuring that the system offers sufficient upgrade capacity and flexibility for future needs such as new applications, additional workstations, and networking.

- Upgrade potential should not be downplayed since most systems reach saturation of the initial configuration much sooner than planned.

- Detailed maintenance data may not be provided by the vendor; other local users may have to be polled. INPUT found that many users do not keep detailed records on maintenance, leaving the evaluator no alternatives to basing his weighting on subjective inputs.

7. USER INTERFACE

- User interface considerations, as shown in Exhibit VII-6, are concerned with physical aspects (workstation layout, functions, etc.) and ease of use issues. Of the two, the latter is probably the most important.

- The evaluating manager must establish the ease of use criteria for his organization. Systems that are very friendly or easy to use for beginner or low-level tasks may be irritatingly cumbersome for more experienced users. If users will be dedicated workstation opeators, system communications flexibility and speed of entry should be stressed; if the operators will be casual, then ease of use is more critical.

8. BENCHMARKING

- Benchmark testing should be considered an integral part of the overall evaluation process, rather than a substitute for a paper review as discussed earlier.

- Benchmarks have two aspects: function testing and performance testing. Performance benchmarks are the most difficult to construct and conduct because they attempt to simulate the anticipated use profile of the system.

- Care should be taken that the benchmarks are representative of actual tasks performed by an organization, and further that they are run on the same system configuration that will be installed.

- Benchmarks must be carefully weighted, keeping in mind that performance results from system to system may show considerable variance while in fact the true variance under everyday conditions would be slight. Performance benchmarks should only be expected to give a rough ranking of systems and identify the clearly unsatisfactory ones.

D. SYSTEM JUSTIFICATION

- The methods and procedures for system justification vary widely from company to company, so this section will only address some of the broader issues for managers to be aware of in preparing justifications.

- The first step is to determine the priorities, needs, and goals of upper management which will be involved in reviewing the system funding request.

- Directly measurable cost savings are usually the leading criteria, but other factors may be considered, or less rigorous conditions applied, to the CAD/CAM justification, depending on upper management concerns.

- The initiating manager should also be sensitive to the fact that upper management needs and perspectives will be different from his and the justification package must be oriented to them to be effective.

- The justification document must be clearly and concisely written, with the target audience in mind. Unfamiliar terms or technical jargon must be avoided. System benefits and the methodologies used for analysis, selection, and justification should be explained simply and clearly.

- The proposal should be well presented and show the approver how the benefits apply to him.

- Although a CAD/CAM system will typically require a detailed justification, the approver should not be burdened with detail. Detail should be made available in a proposal appendix for reference as needed.

- The preparer should seek help in areas outside his experience such as the detailed financial analysis. Involving specialists can add to the credibility of the document. Potential sources of assistance or guidance are other organizations such as finance, data processing, manufacturing, the vendor, other users, and outside consultants.

- Previous justifications can serve as models, but the preparer must be aware that the situation may have changed and priorities or perspectives shifted.

- While the justification assumptions must be well founded, they must also represent achievable goals. There is always a temptation to make the

justification look extremely positive, but it should be remembered that the proposal becomes a measurement tool after approval.

- Managers should not hesitate to address less tangible issues such as improved employee morale, improved management control, or long-term potential such as CAM integration, or enhanced management information systems. It may not be possible to associate a cost savings with them, but they should be addressed as side issues if they are of benefit or interest to the approver.

- Task and process models should be developed to establish and verify the justification assumptions. The greatest difficulty in this process is establishing a level of detail for the model which will yield reliable results without getting bogged down with detailed processes.

- Cost savings are rigorously pursued in justifications, but added costs are sometimes overlooked, which can be detrimental to the preparer. The total operating environment must be examined to avoid future problems. Some examples of items that might be ignored are:

  - Lost productivity during formal training and while on the learning curve.

  - Decreased system availability during start-up due to new system problems and sub-optimum system tuning and management.

  - Added facilities costs such as flooring, partitions, lighting, power, and temperature/humidity control.

  - Rework of standards and procedures.

  - Added management costs or decreased management productivity during start-up and on-going.

  - Added internal support for programming and system operations.

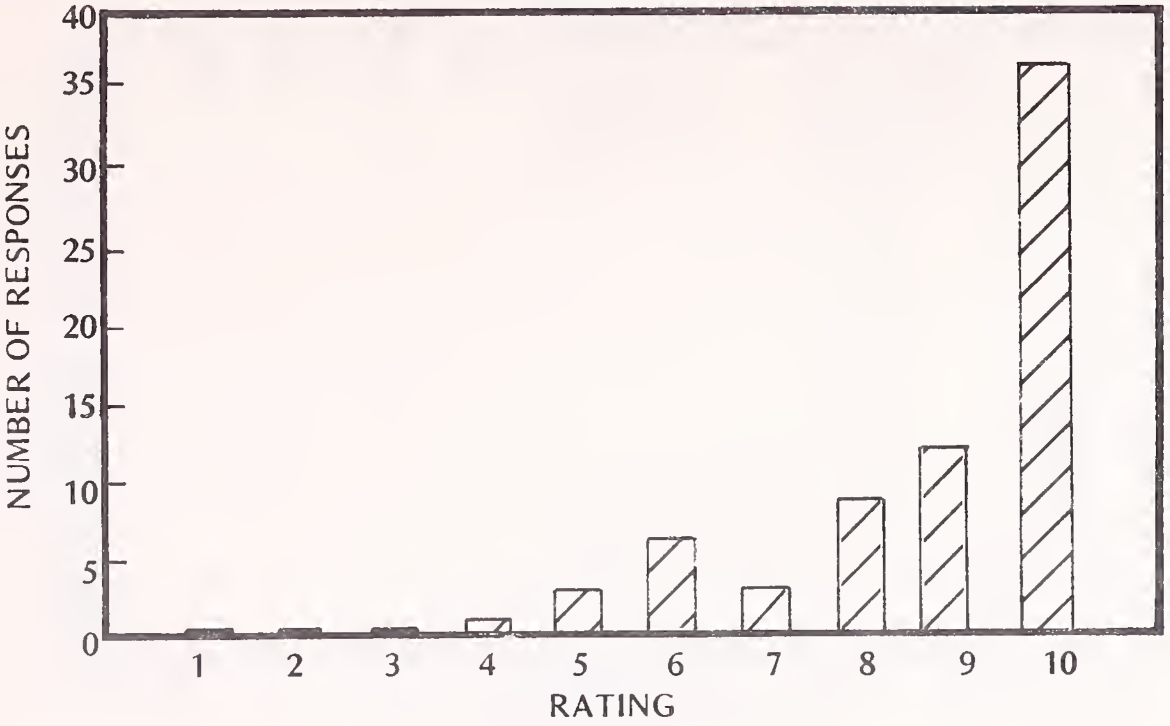
- Continuing training which results in lost productivity plus outside expense or internal course development expenses.

APPENDIX A: DATA BASE

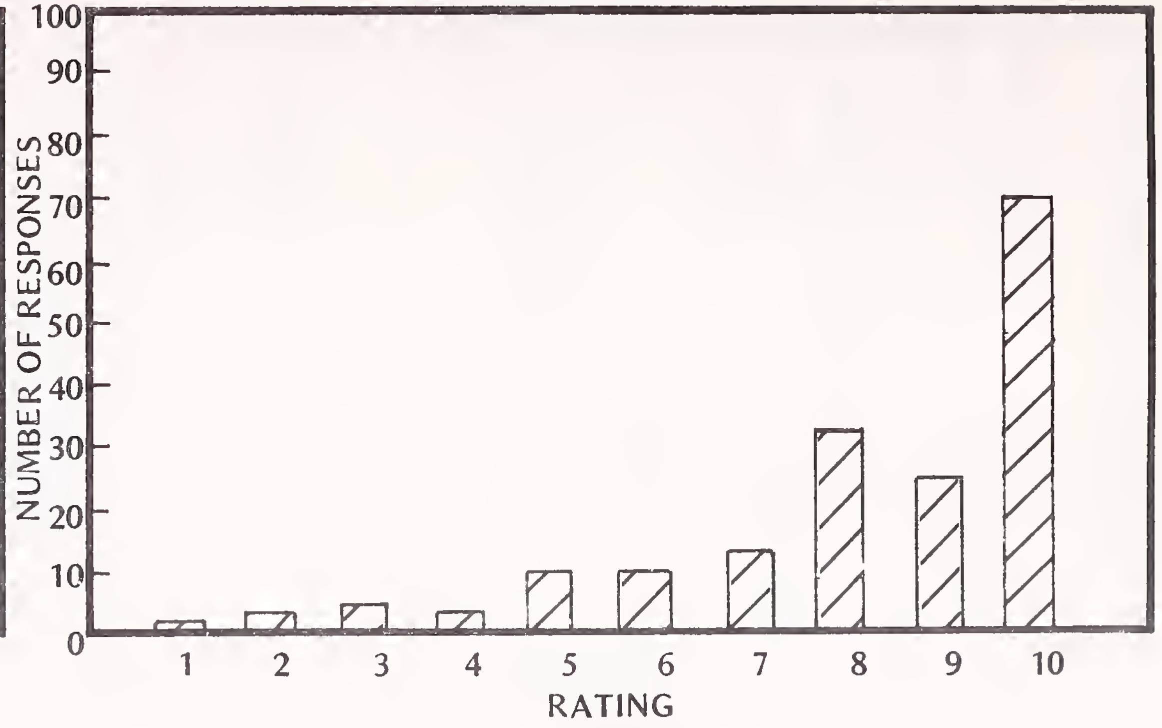
EXHIBIT A-1

USER RATINGS - SYSTEM JUSTIFICATION FACTORS, COST SAVINGS

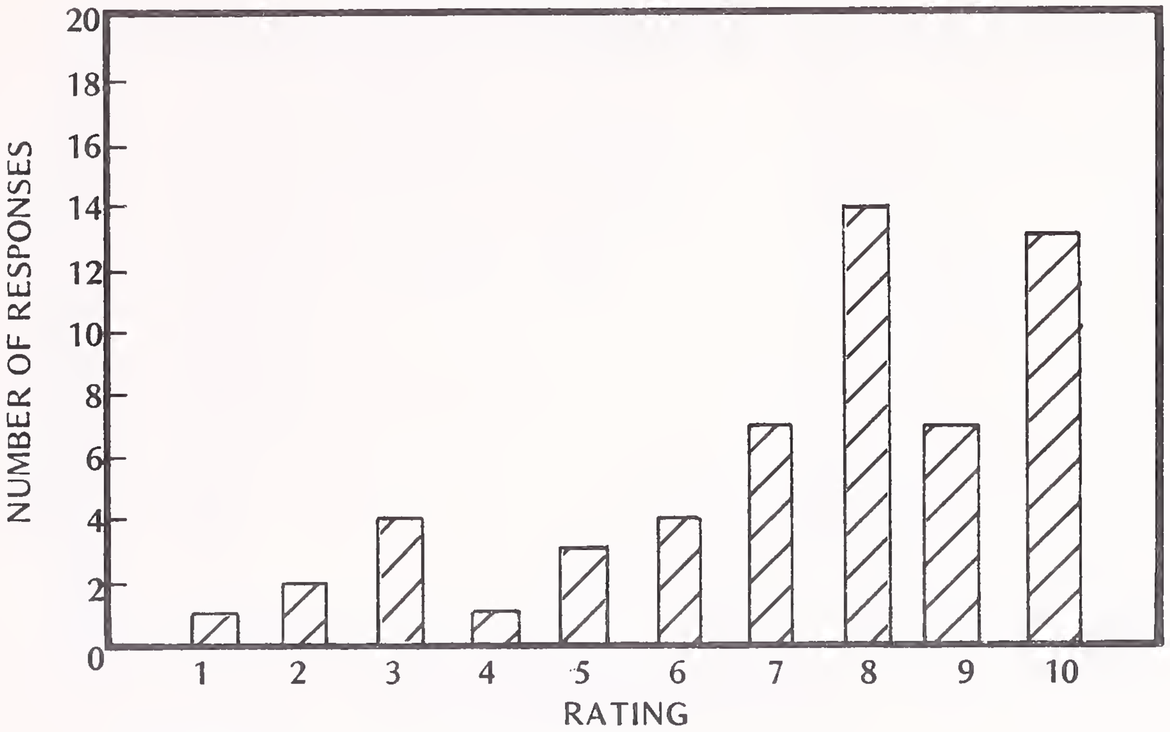
MECHANICAL APPLICATIONS
MEAN = 8.8



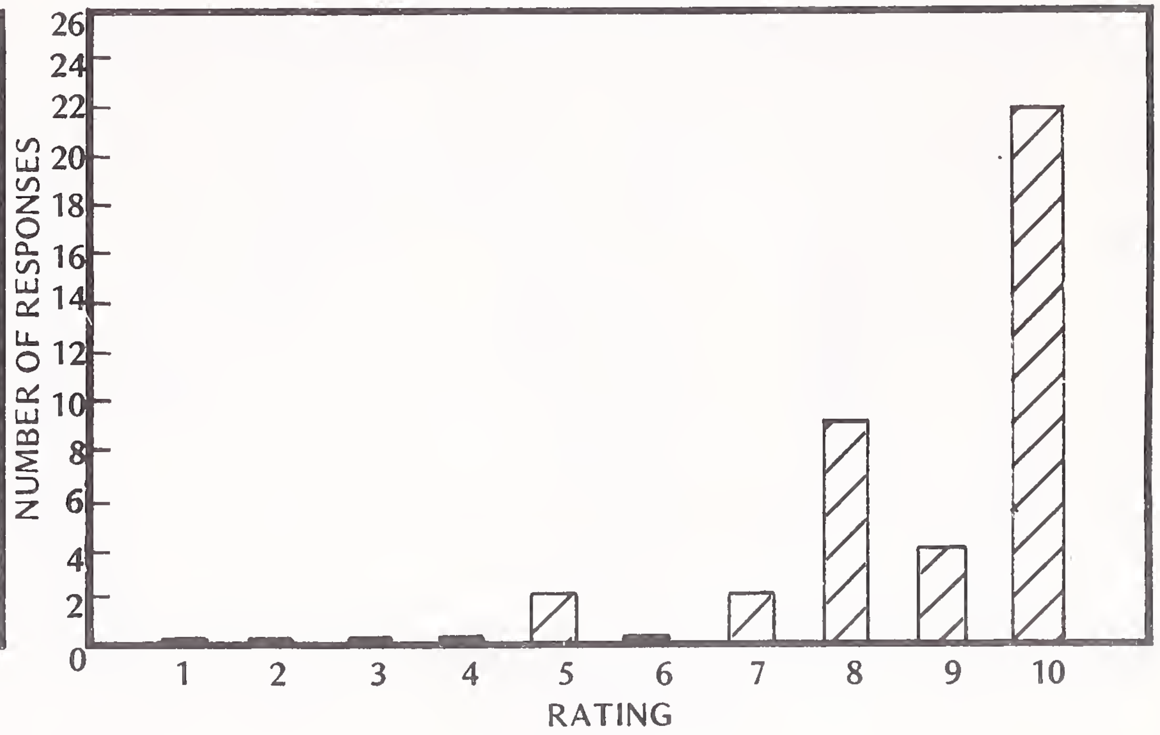
ALL APPLICATIONS
MEAN = 8.3



ELECTRONICS APPLICATIONS
MEAN = 7.3



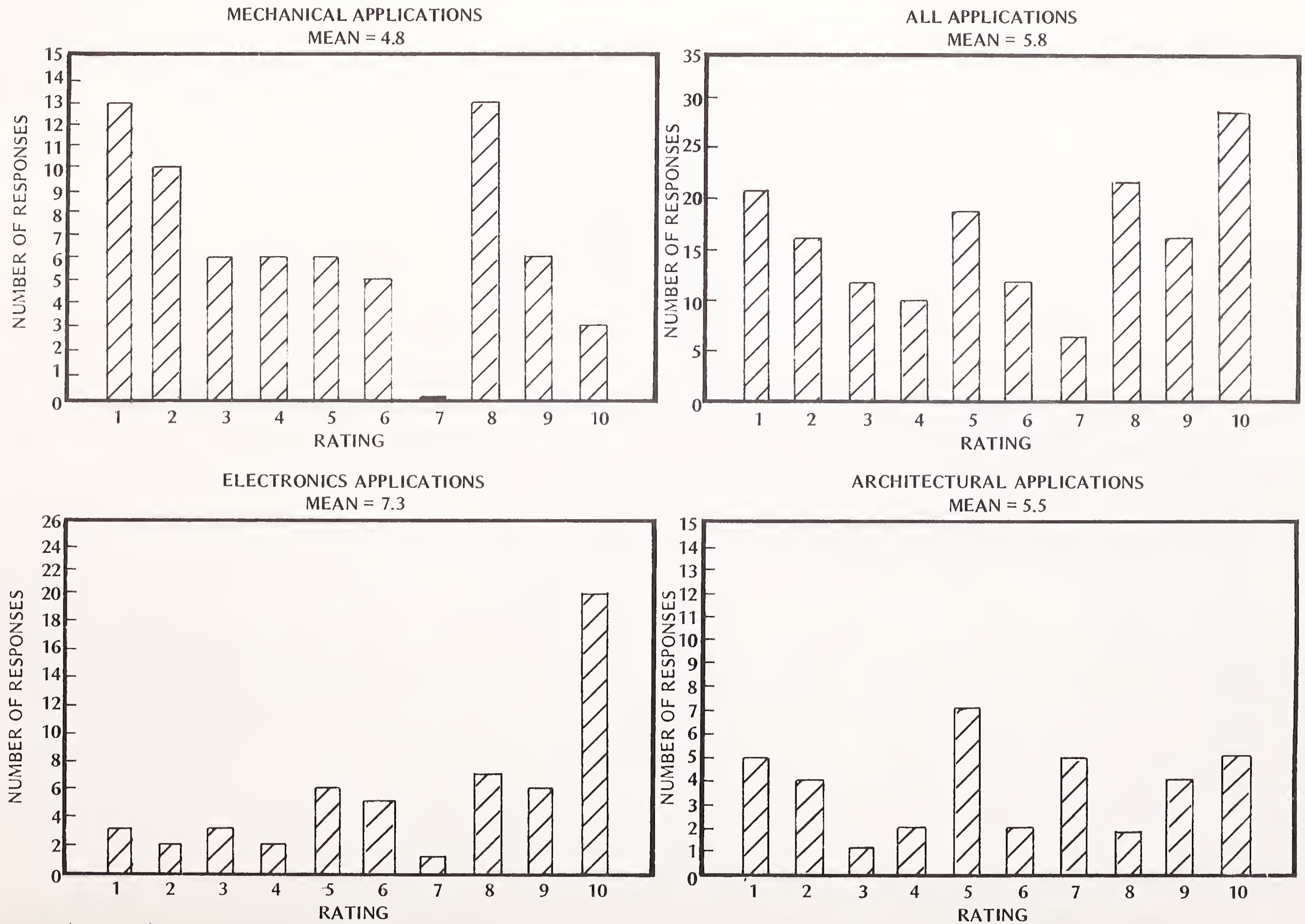
ARCHITECTURAL APPLICATIONS
MEAN = 9.0



(Field 161)
1 = NOT IMPORTANT, 10 = VITAL
*EXHIBIT III-1 — Detail

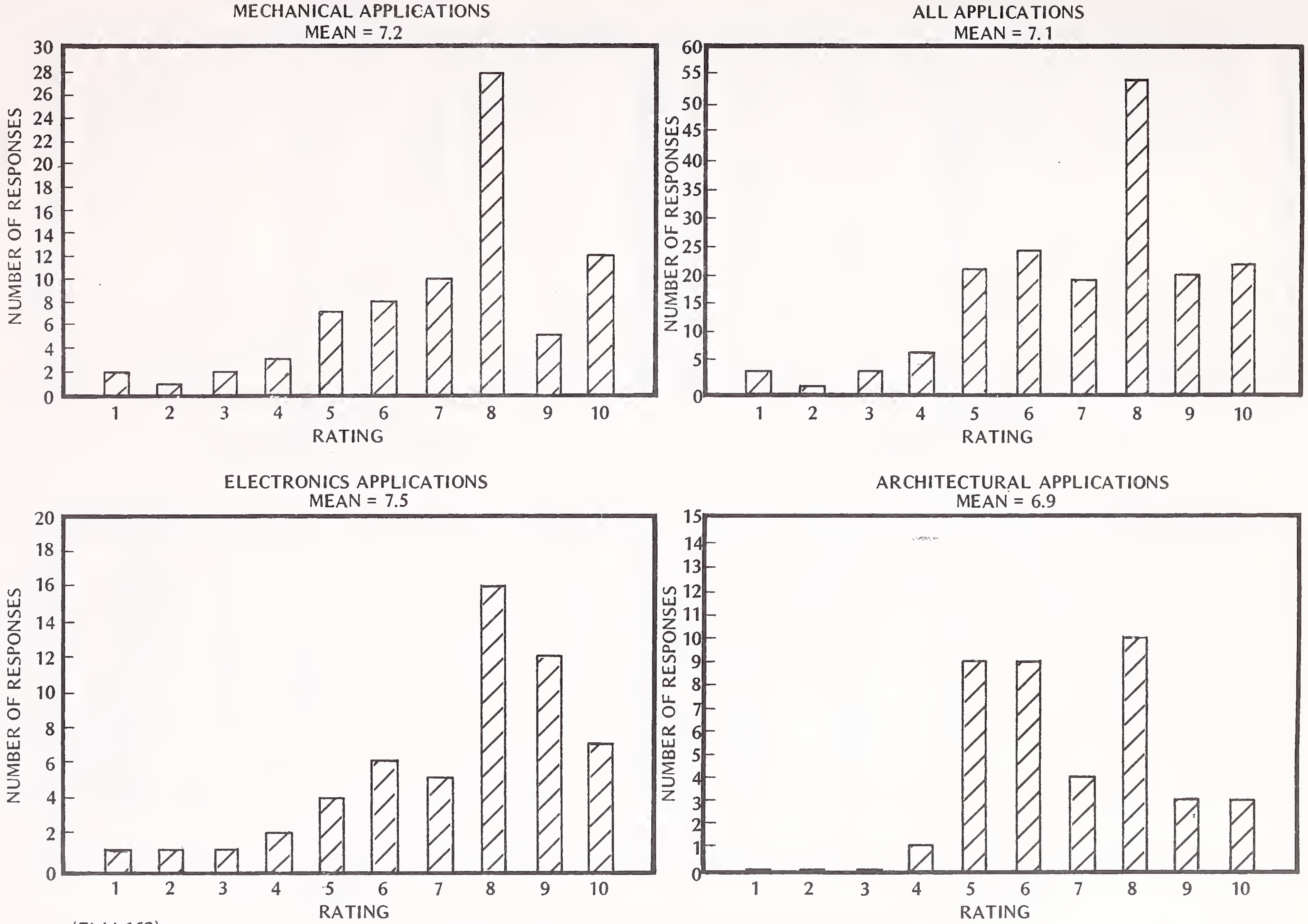
EXHIBIT A-2*

USER RATINGS - SYSTEM JUSTIFICATION FACTORS,
DESIGNS/PROJECTS CANNOT BE DONE WITHOUT CAD/CAM



(Field 163)
1 = NOT IMPORTANT, 10 = VITAL
*EXHIBIT III-2 — Detail

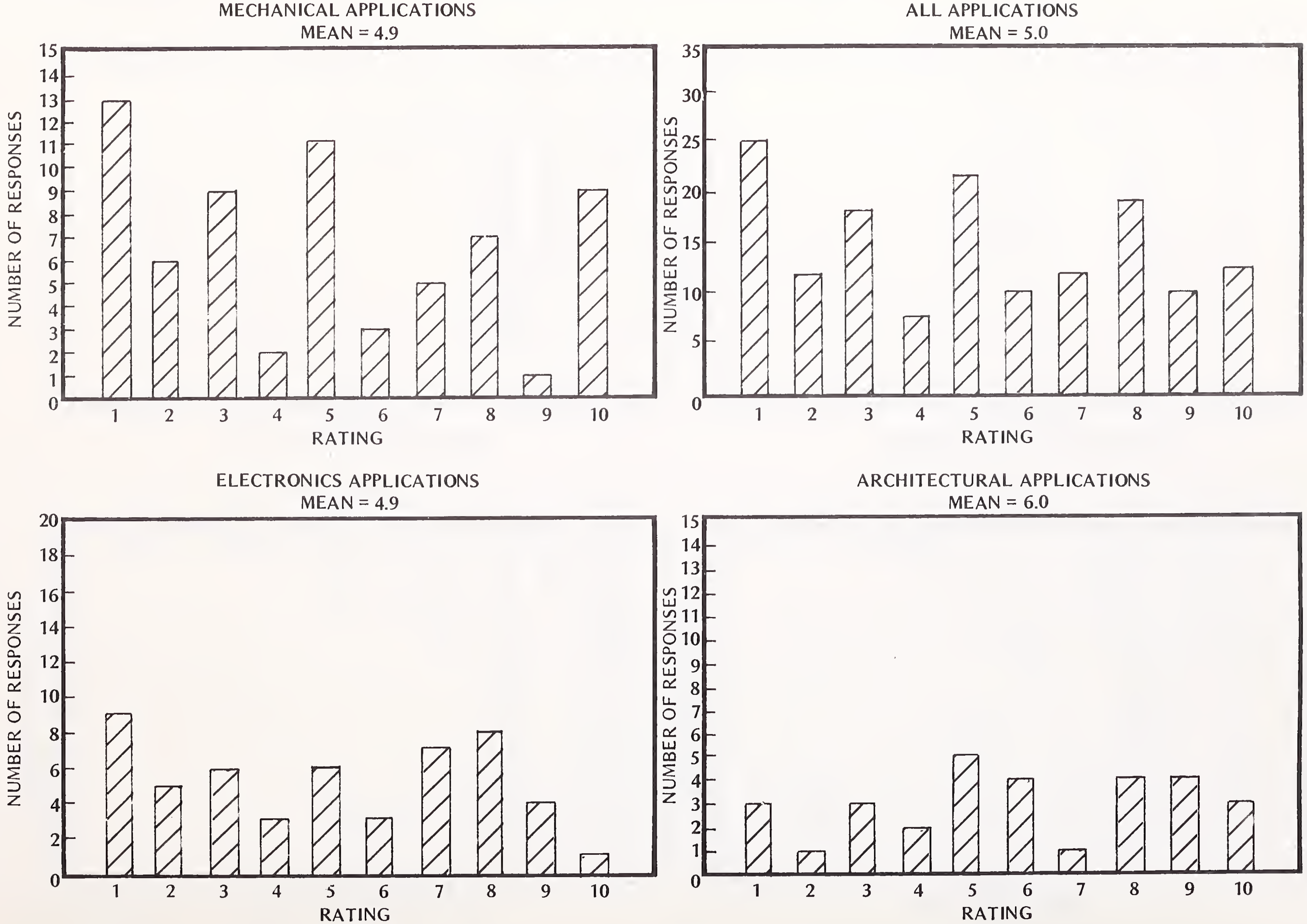
USER RATINGS - SYSTEM JUSTIFICATION FACTORS, IMPROVED DESIGN/DRAFTING QUALITY



(Field 162)
1 = NOT IMPORTANT, 10 = VITAL *EXHIBIT III-3 — Detail

EXHIBIT A-4*

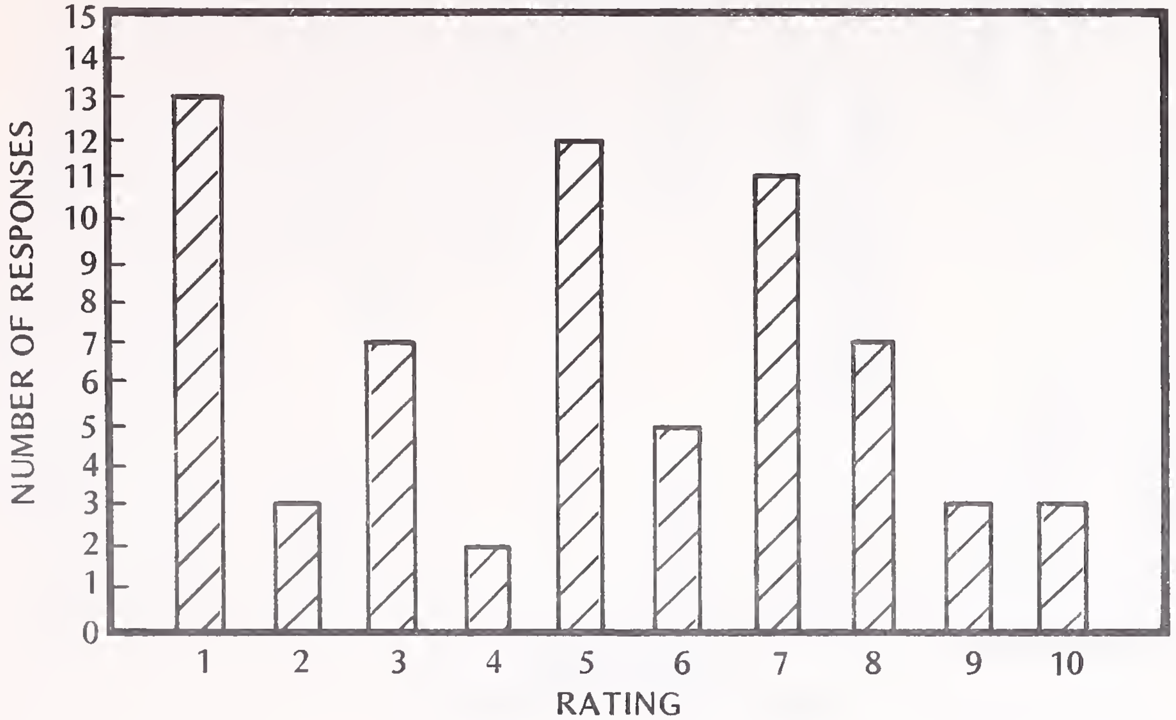
USER RATINGS - SYSTEM JUSTIFICATION FACTORS, INCREASED OPERATIONS EFFICIENCY



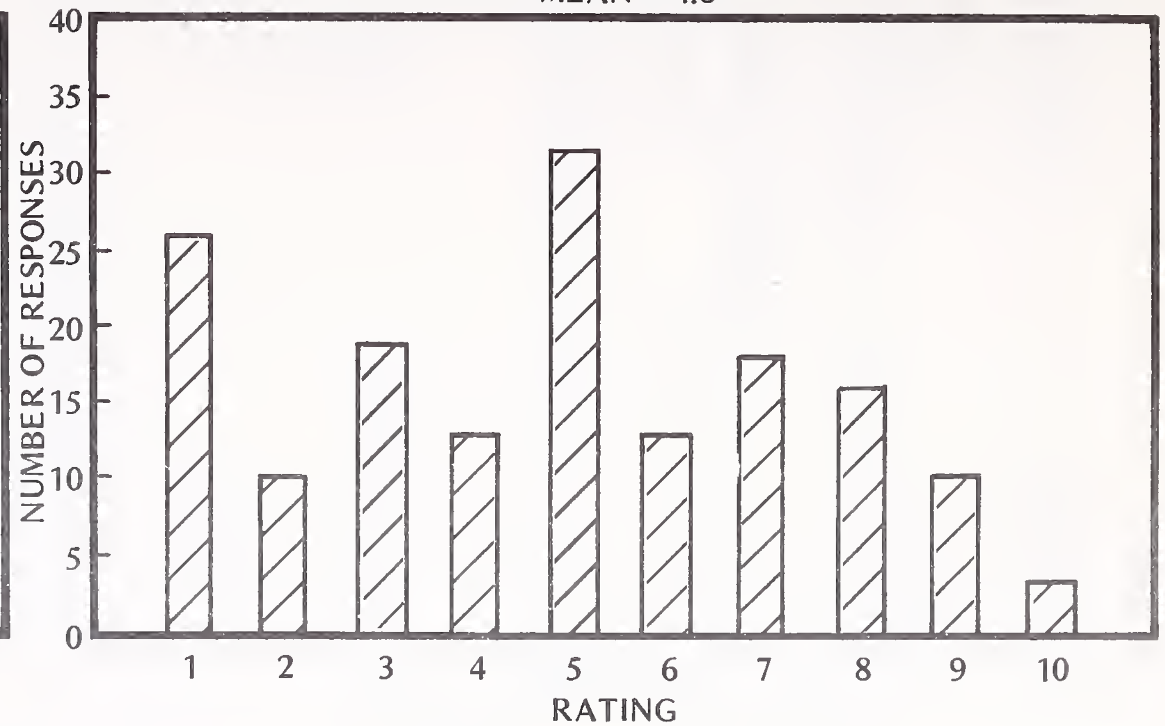
(Field 165)
1 = NOT IMPORTANT, 10 = VITAL ELECTRONICS
*EXHIBIT III-4 — Detail

USER RATINGS - SYSTEM JUSTIFICATION FACTORS, EMPLOYEE MORALE

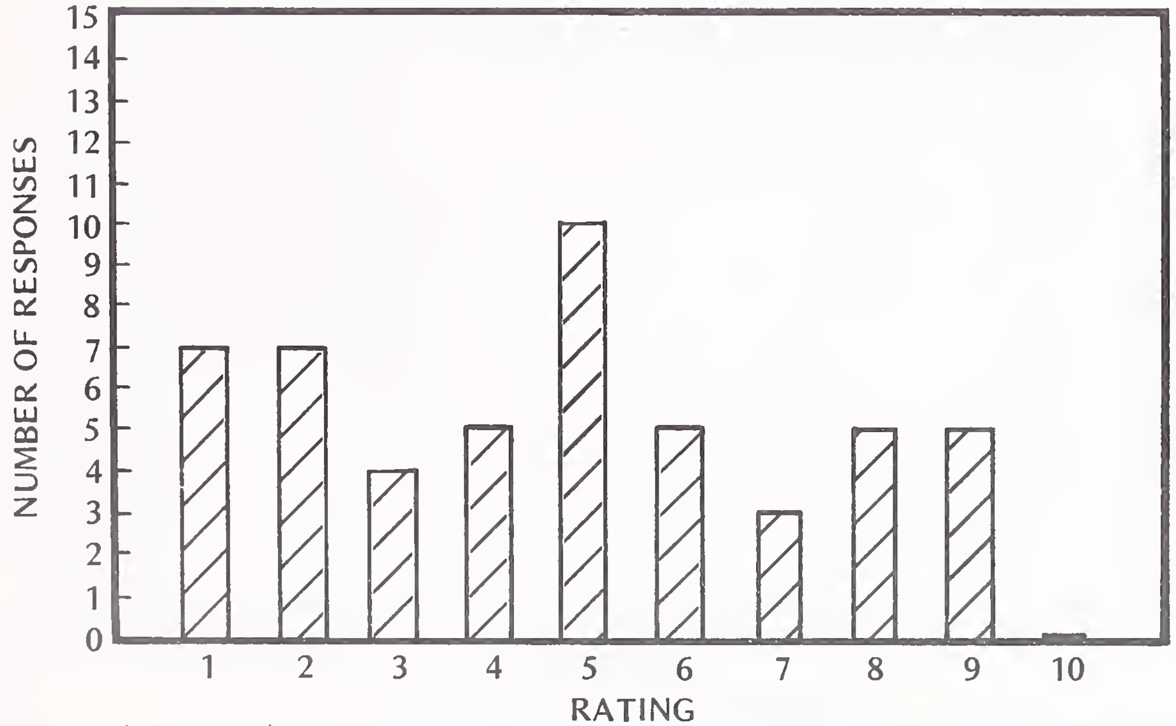
MECHANICAL APPLICATIONS
MEAN = 5.0



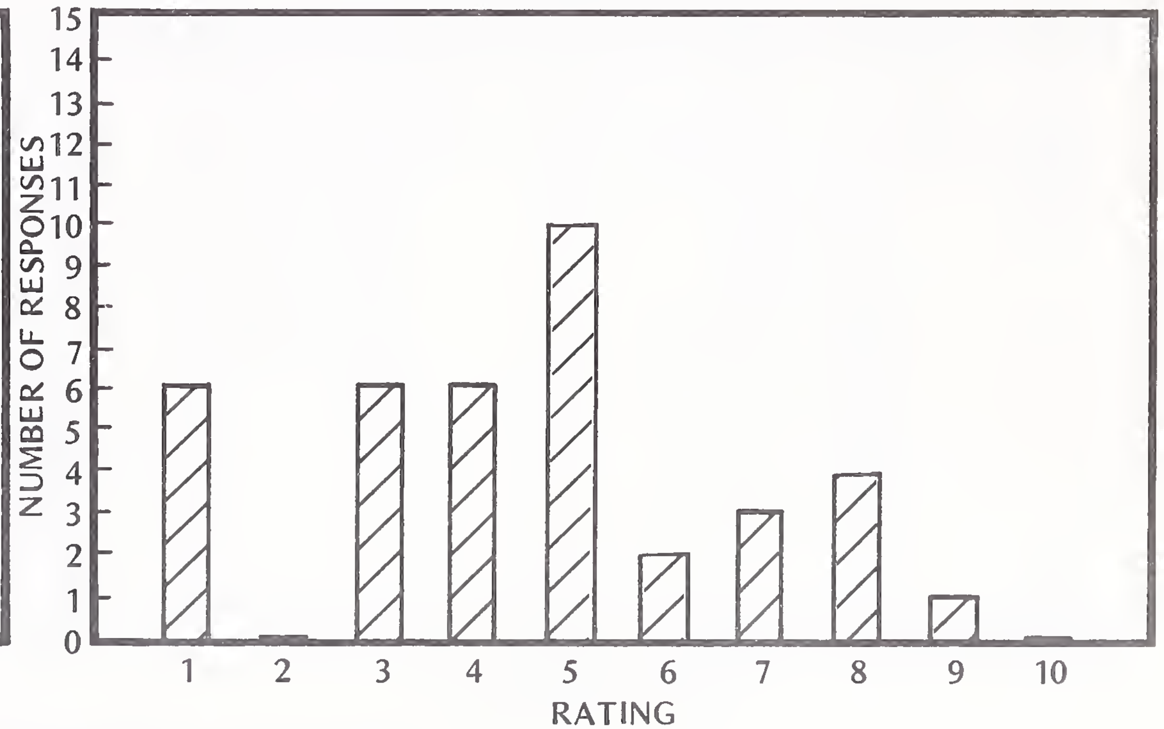
ALL APPLICATIONS
MEAN = 4.8



ELECTRONICS APPLICATIONS
MEAN = 4.7



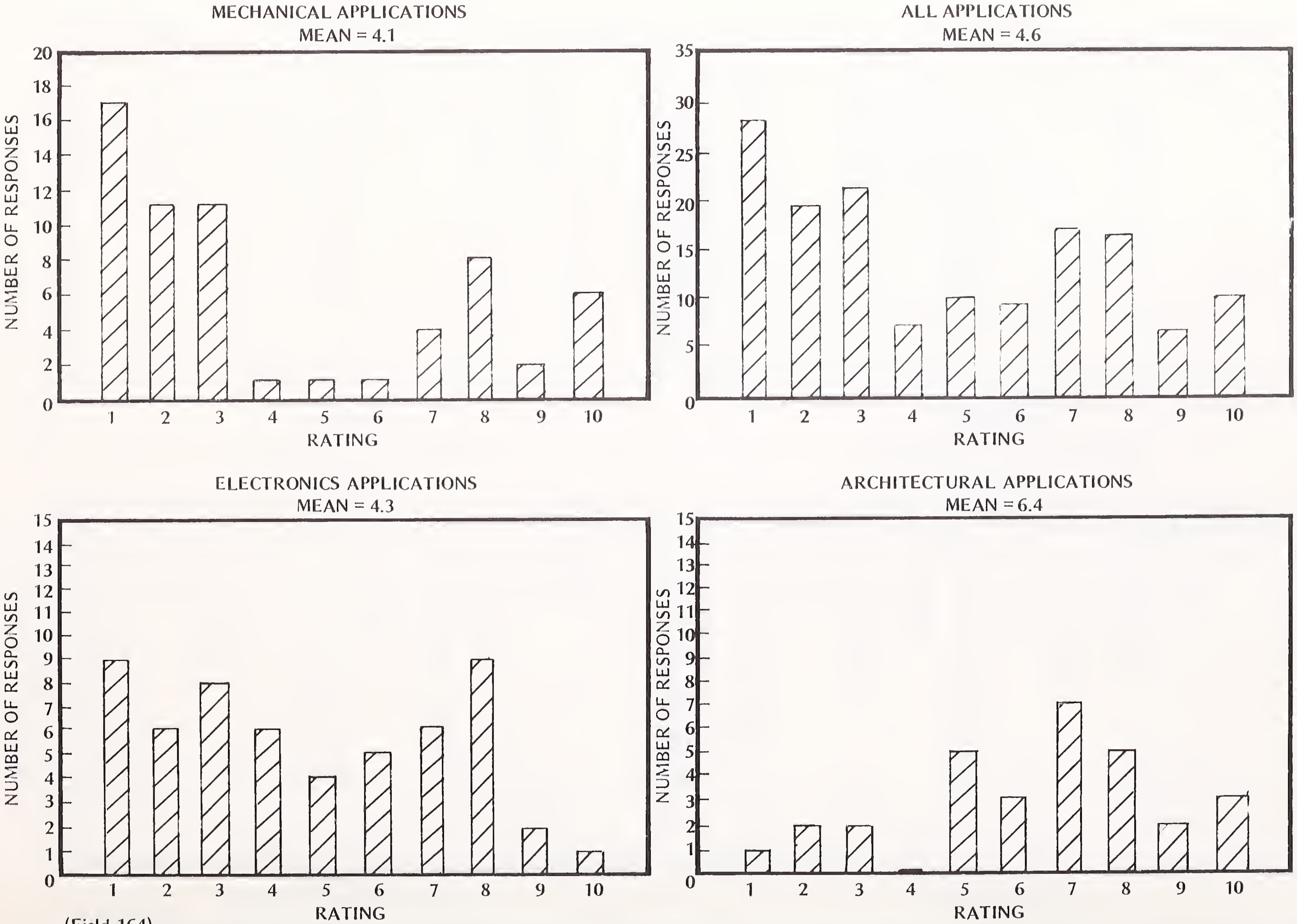
ARCHITECTURAL APPLICATIONS
MEAN = 4.5



(Field 166)
1 = NOT IMPORTANT, 10 = VITAL
*EXHIBIT III-5 – Detail

EXHIBIT A-6*

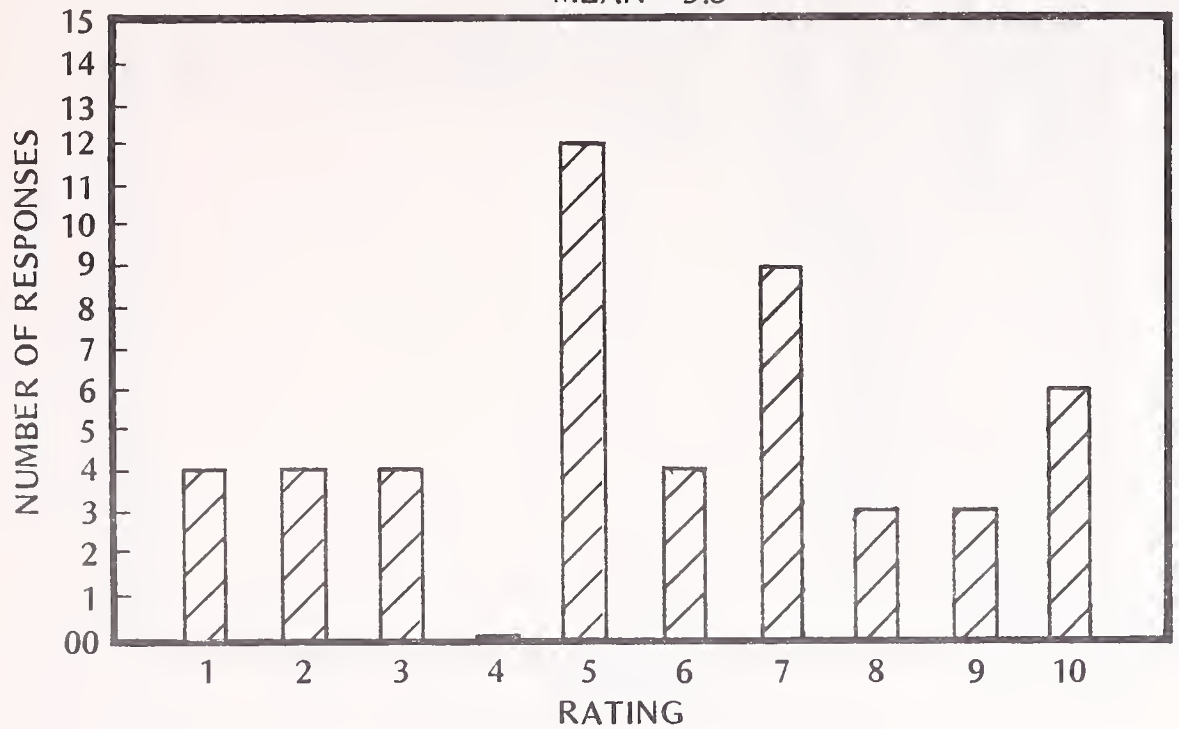
USER RATINGS - SYSTEM JUSTIFICATION FACTORS, MORE EFFICIENT RESOURCE LOADING



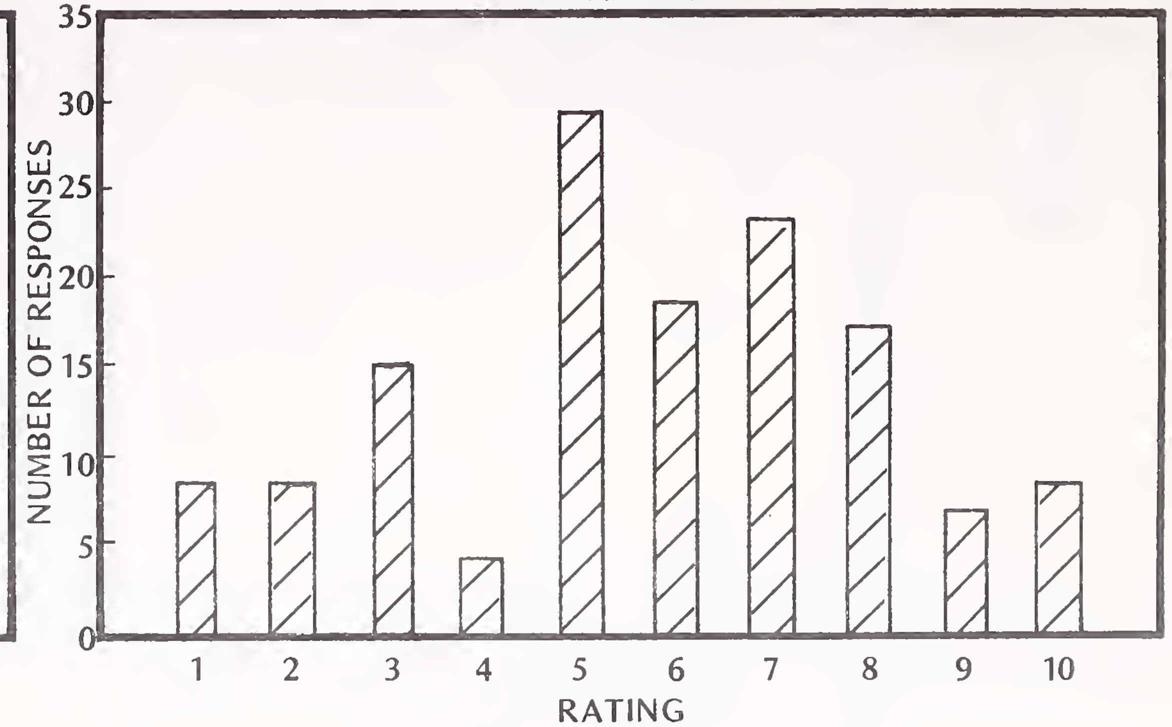
(Field 164)
1 = NOT IMPORTANT, 10 = VITAL
*EXHIBIT III-6 – Detail

INPUT
XCADU

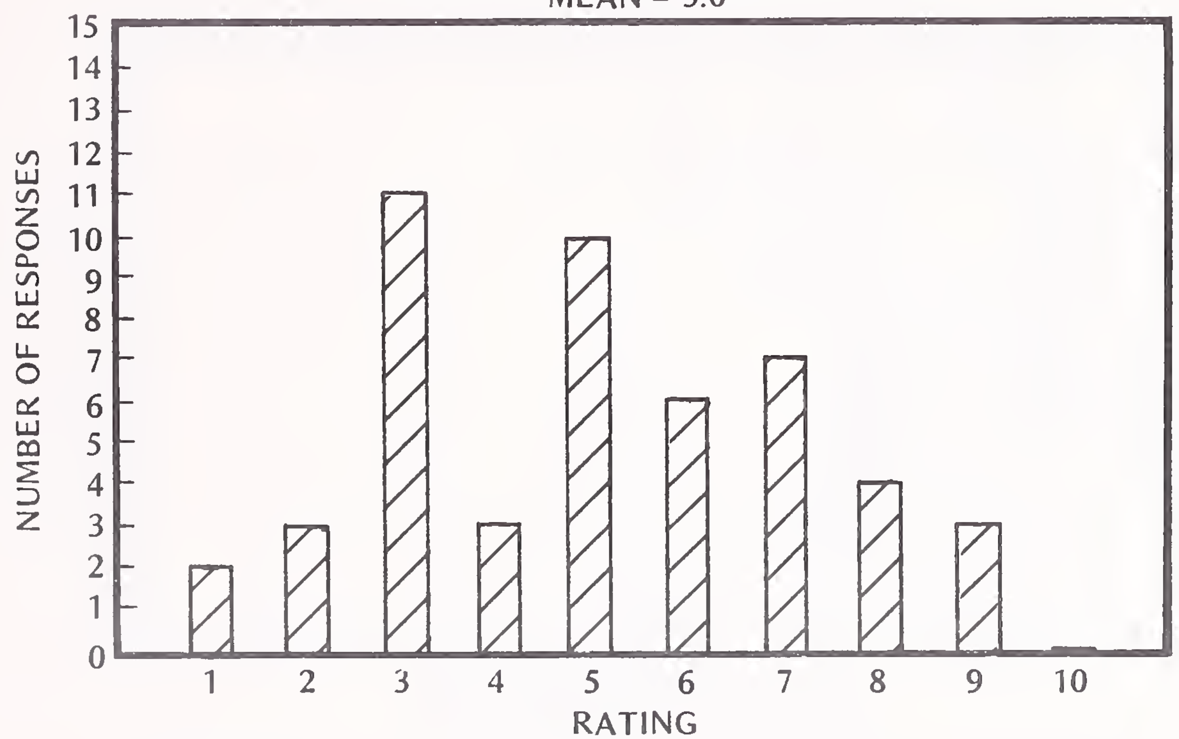
MECHANICAL APPLICATIONS
MEAN = 5.8



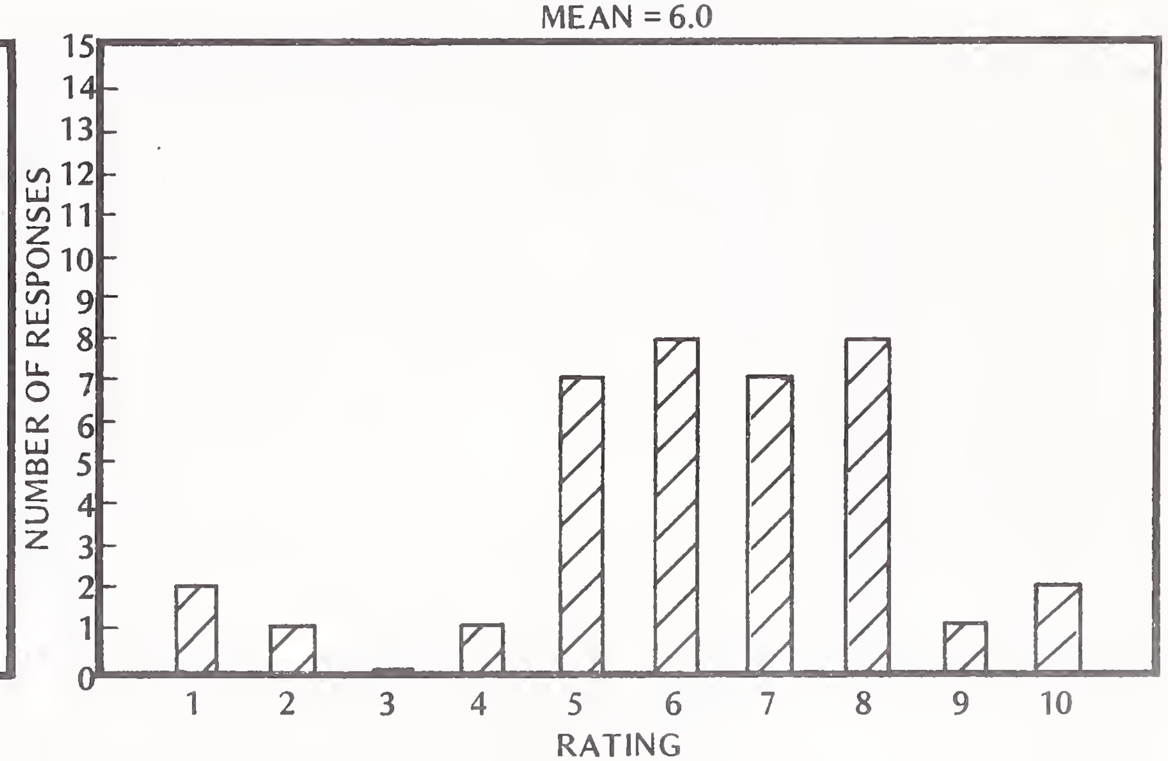
ALL APPLICATIONS
MEAN = 5.6



ELECTRONIC APPLICATIONS
MEAN = 5.0



ARCHITECTURAL APPLICATIONS
MEAN = 6.0

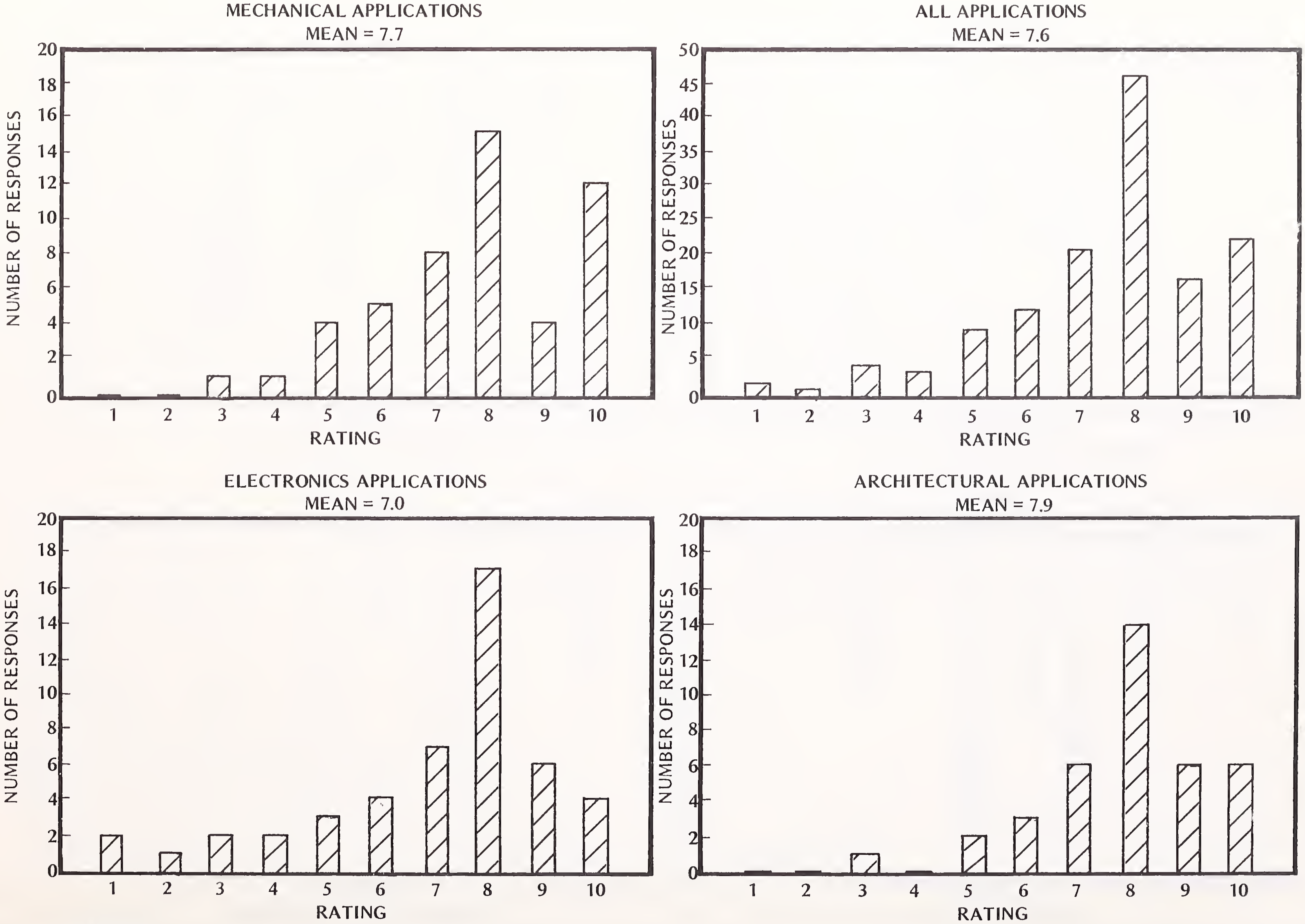


(Field 82)
1 = NO IMPACT, 10 = MAJOR IMPACT

*EXHIBIT III-7 — Detail

EXHIBIT A-8*

SYSTEM SELECTION FACTORS, PROCESSING CAPABILITIES

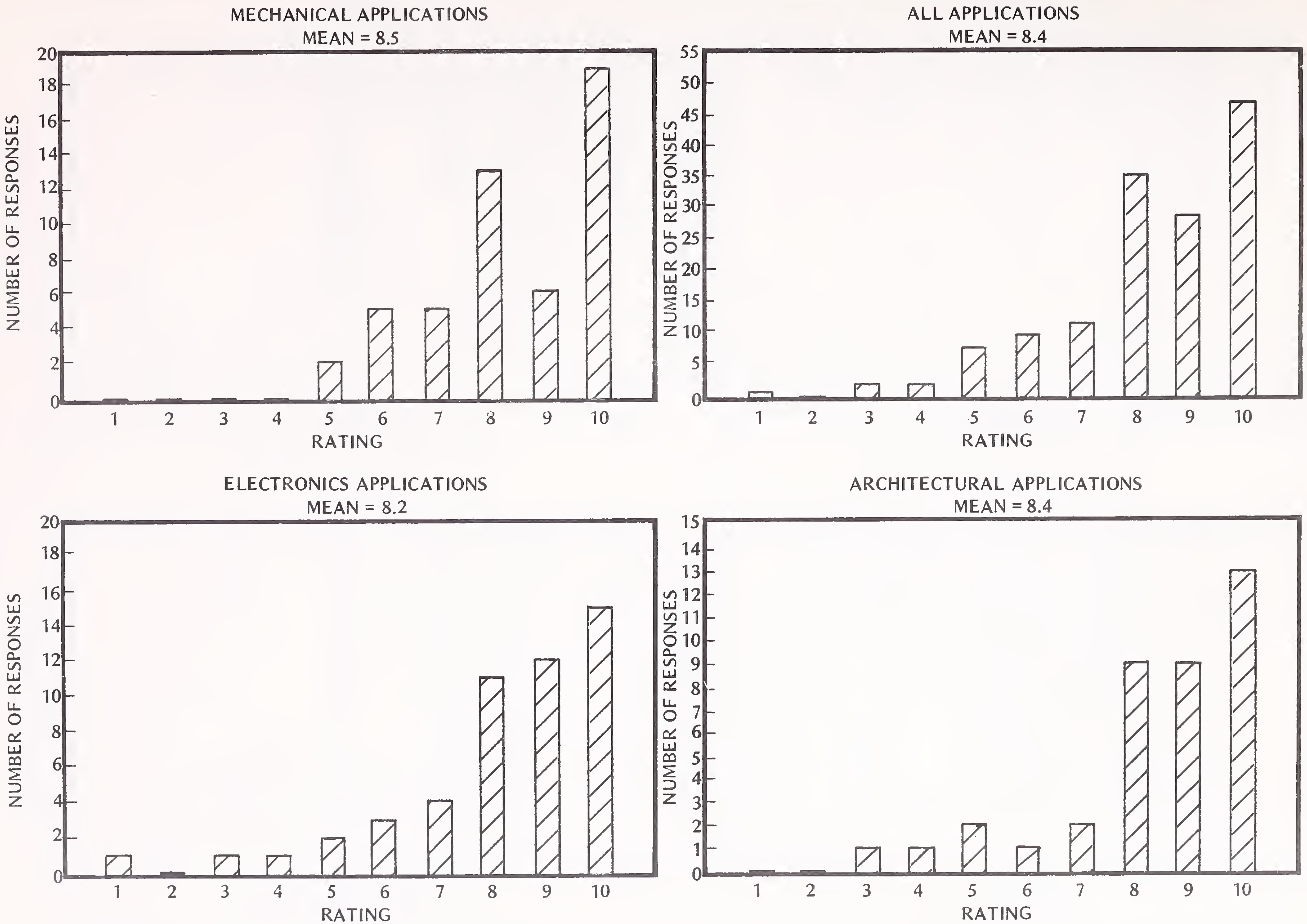


(Field 86)
1 = NO IMPACT, 10 = MAJOR IMPACT

*EXHIBIT III-8 – Detail

EXHIBIT A-9*

SYSTEM SELECTION FACTORS, SOFTWARE CAPABILITIES

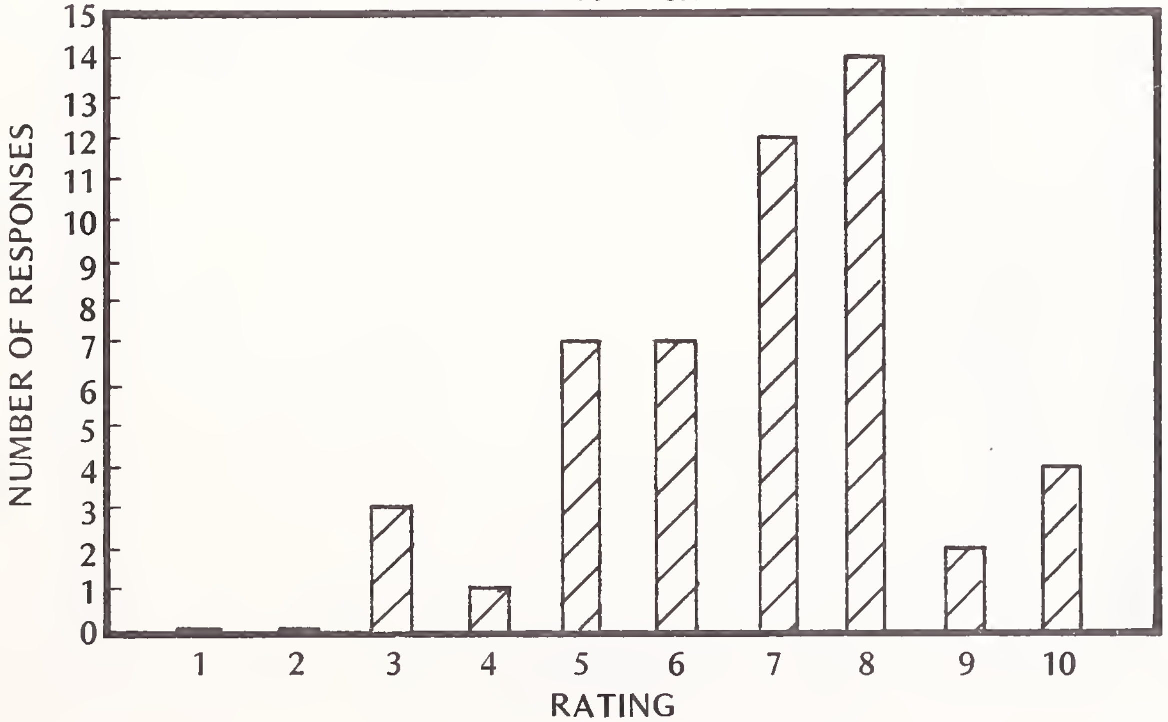


(Field 90)
1 = NO IMPACT, 10 = MAJOR IMPACT   *EXHIBIT III-9 – Detail

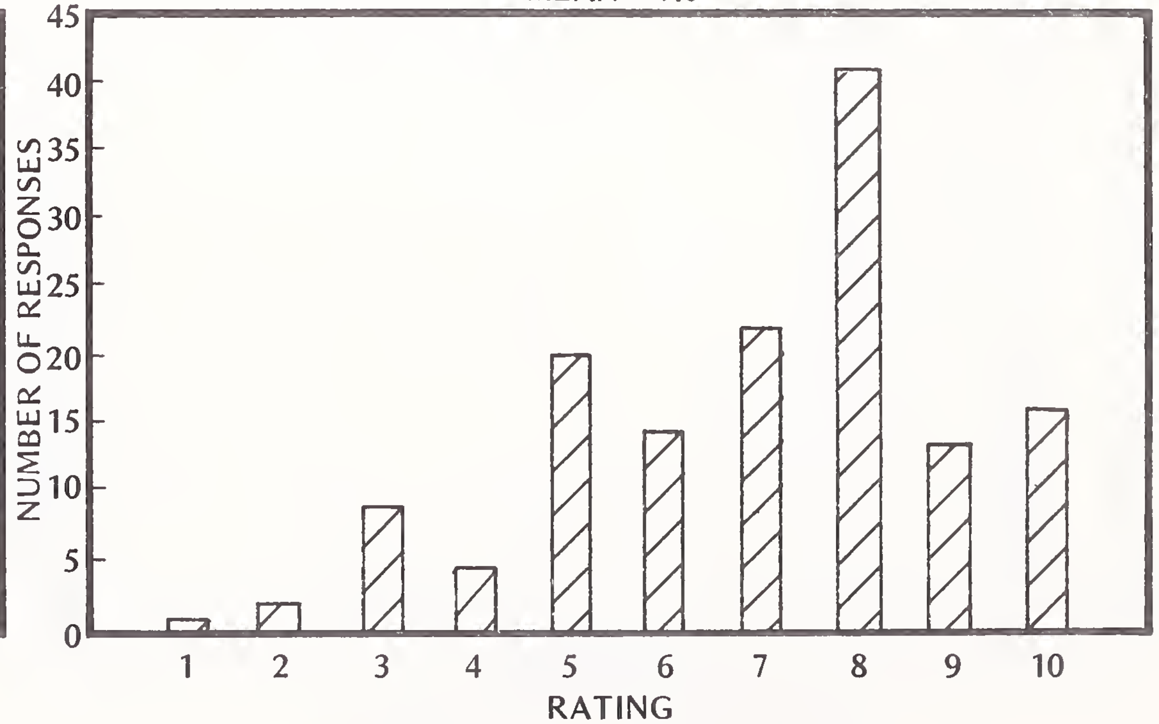
EXHIBIT A-10*

SYSTEM SELECTION FACTORS, FUTURE ENHANCEMENTS

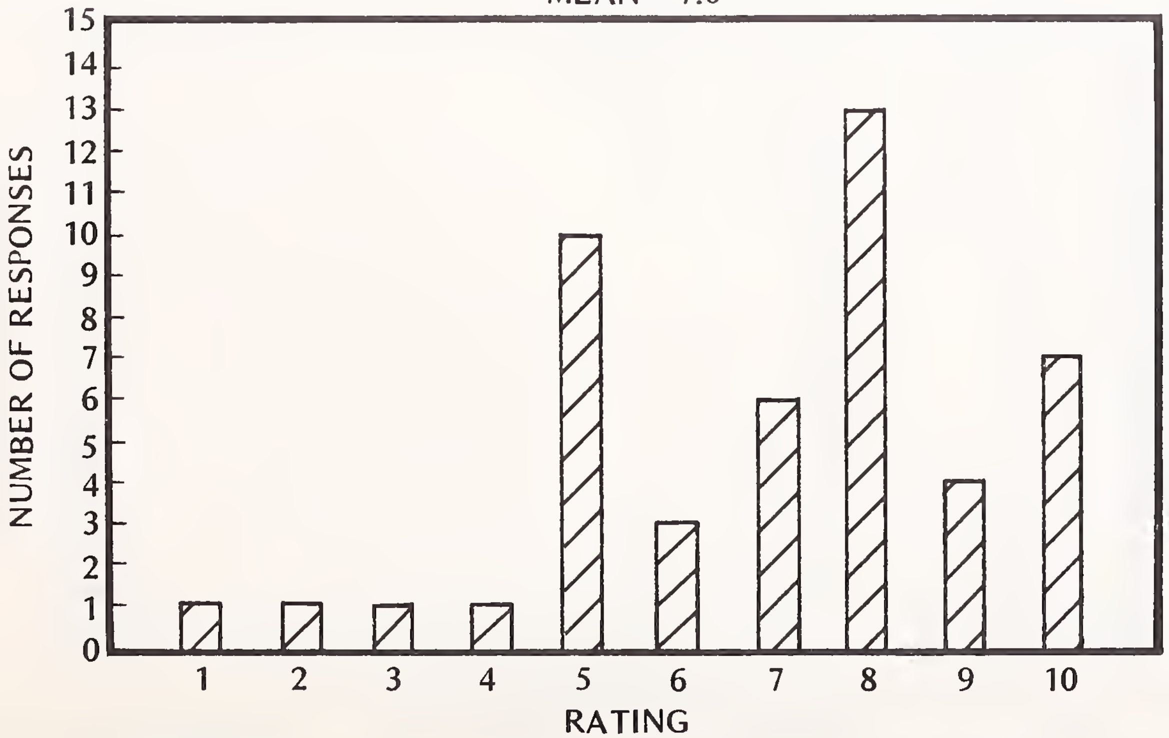
MECHANICAL APPLICATIONS
MEAN = 6.8



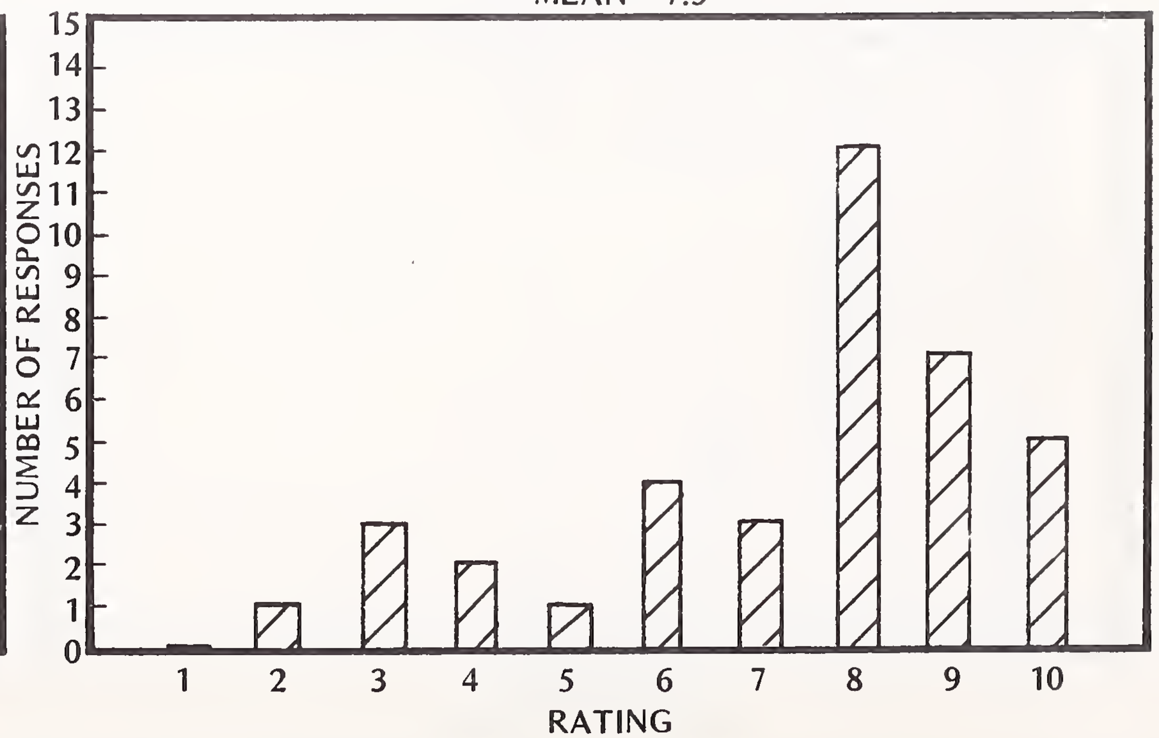
ALL APPLICATIONS
MEAN = 7.0



ELECTRONICS APPLICATIONS
MEAN = 7.0



ARCHITECTURAL APPLICATIONS
MEAN = 7.3

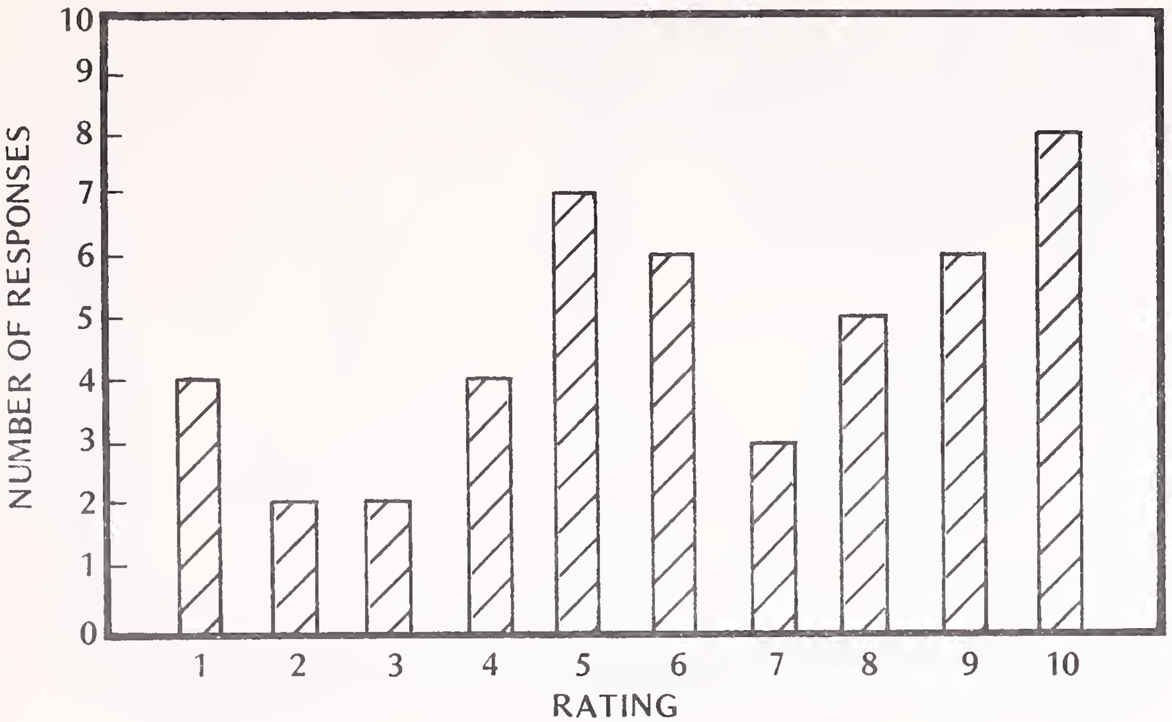


(Field 102)
1 = NO IMPACT, 10 = MAJOR IMPACT

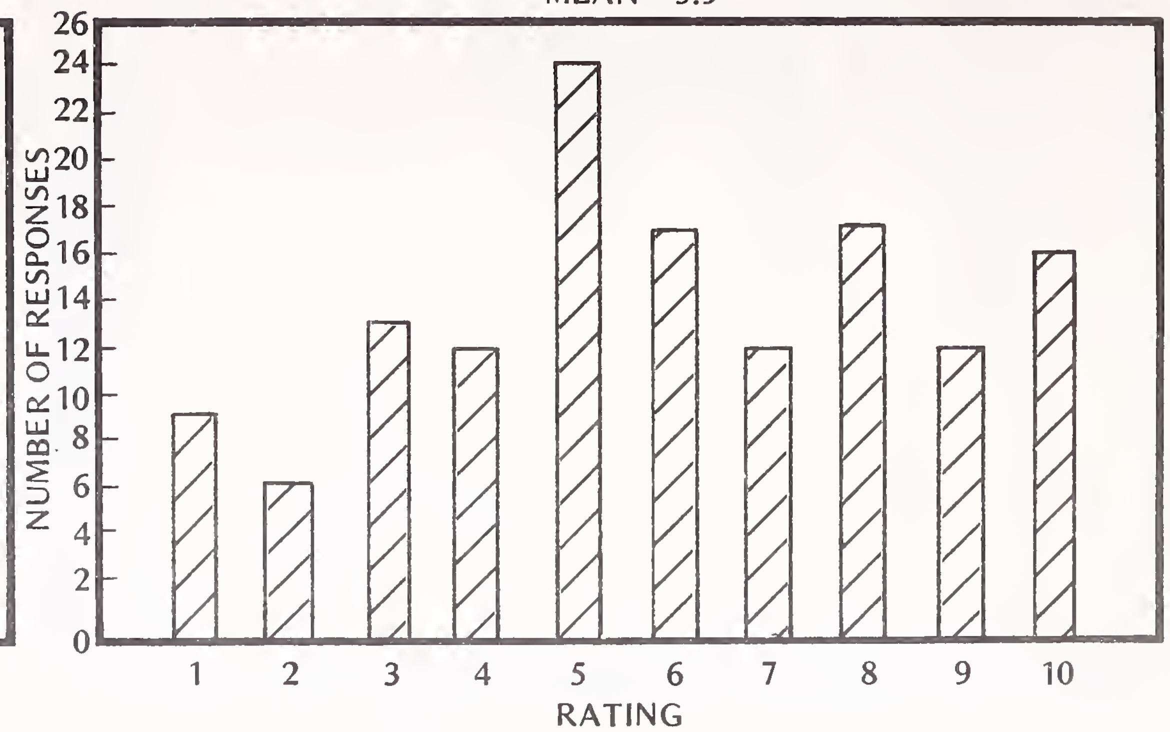
*EXHIBIT III-10 – Detail

SYSTEM SELECTION FACTORS, ACCESS TO DATA BASES

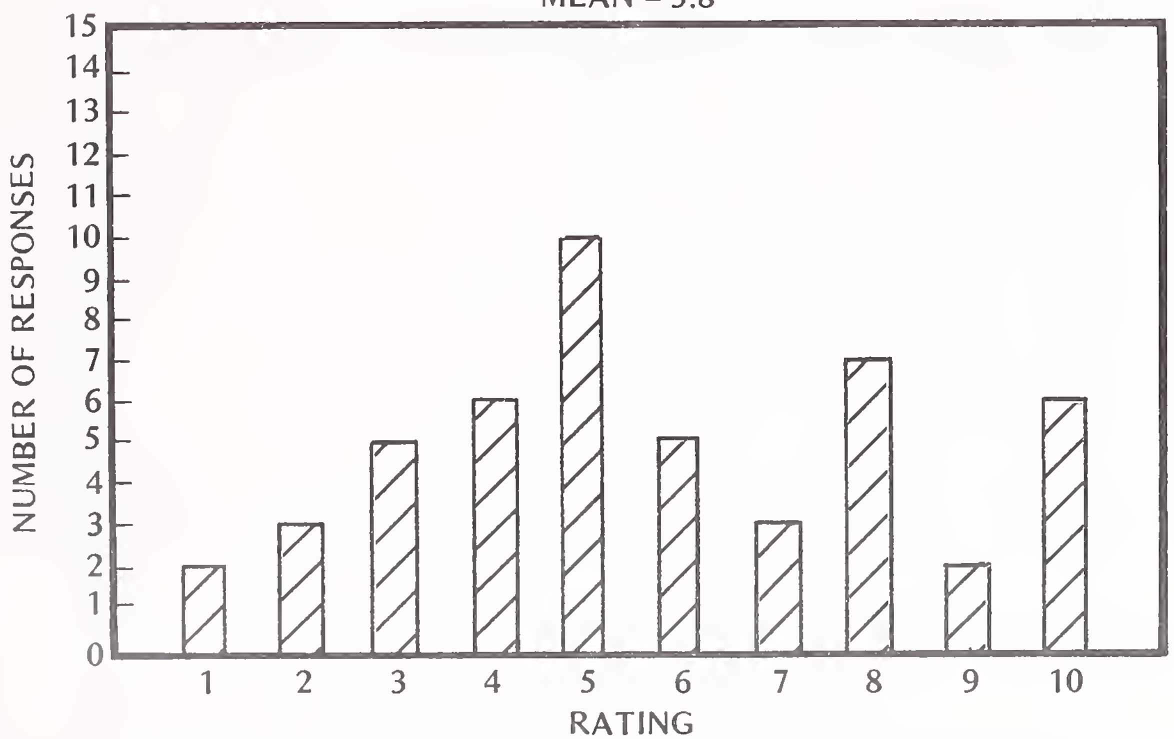
MECHANICAL APPLICATIONS
MEAN = 6.3



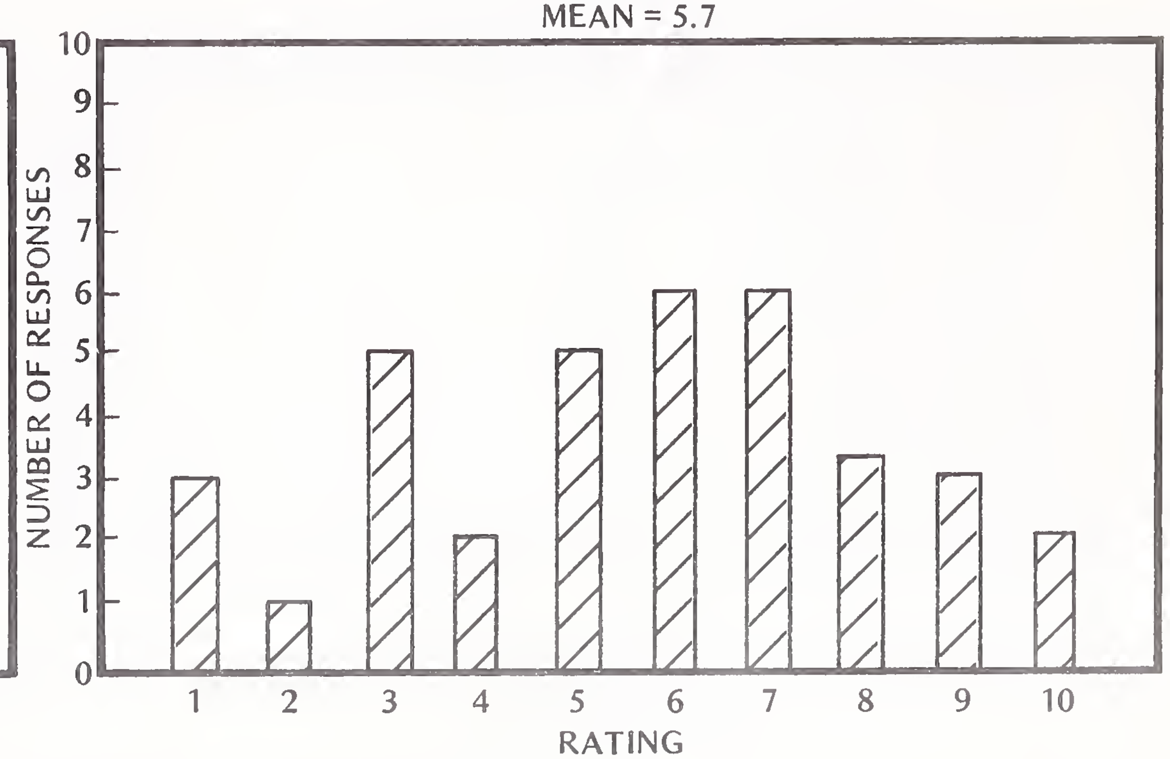
ALL APPLICATIONS
MEAN = 5.9



ELECTRONICS APPLICATIONS
MEAN = 5.8



ARCHITECTURAL APPLICATIONS
MEAN = 5.7

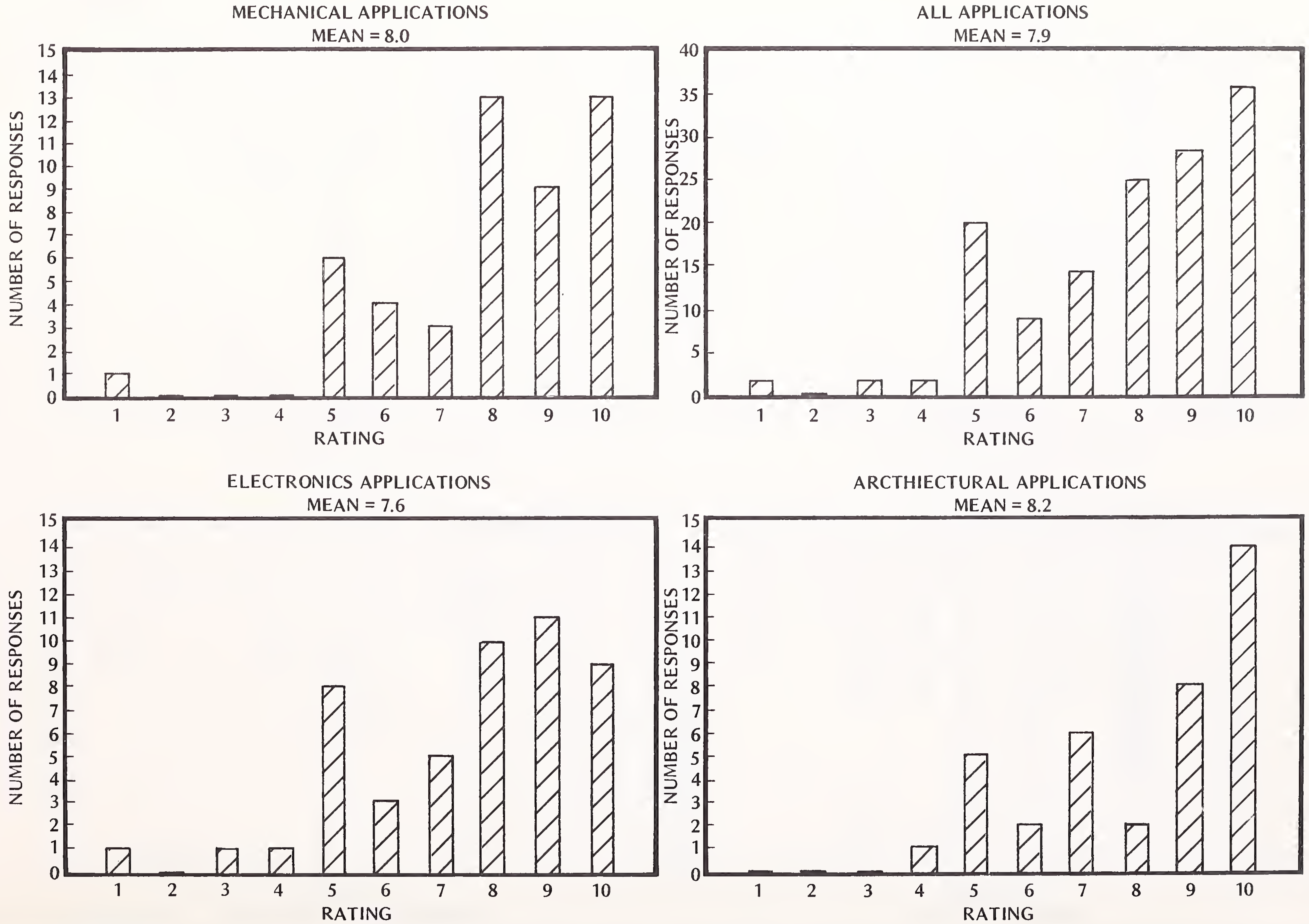


(Field 98)
1 = NO IMPACT, 10 = MAJOR IMPACT

*EXHIBIT III-11 – Detail

EXHIBIT A-12*

SYSTEM SELECTION FACTORS, SYSTEM FLEXIBILITY

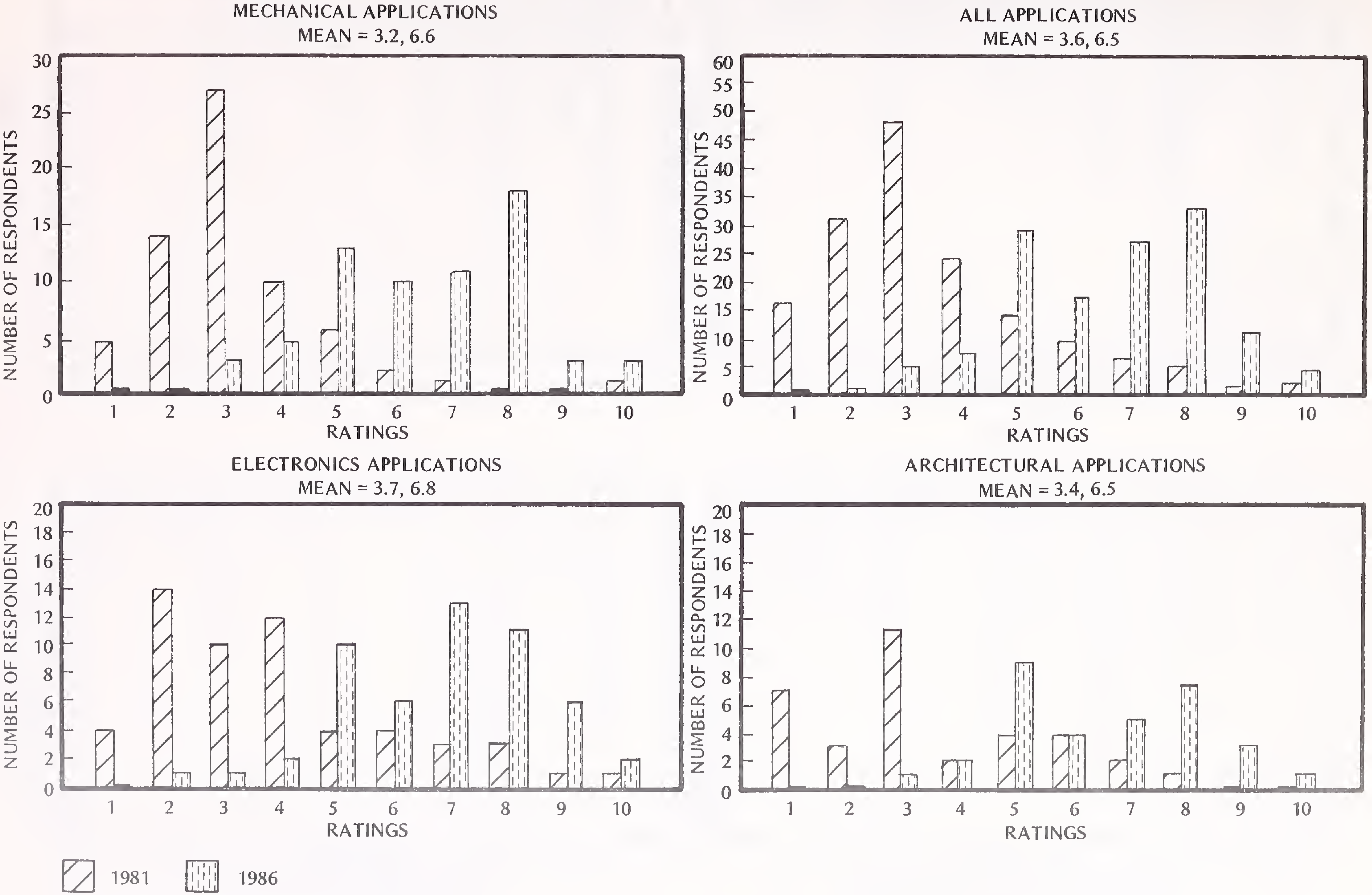


(Field 94)
1 = NO IMPACT, 10 = MAJOR IMPACT

*EXHIBIT III-12 – Detail

EXHIBIT A-13*

USER RATINGS - STATUS OF CAD/CAM INTEGRATION



(Field 302) (Field 303)
1 = NO PROGRESS, 10 = COMPLETELY INTEGRATED

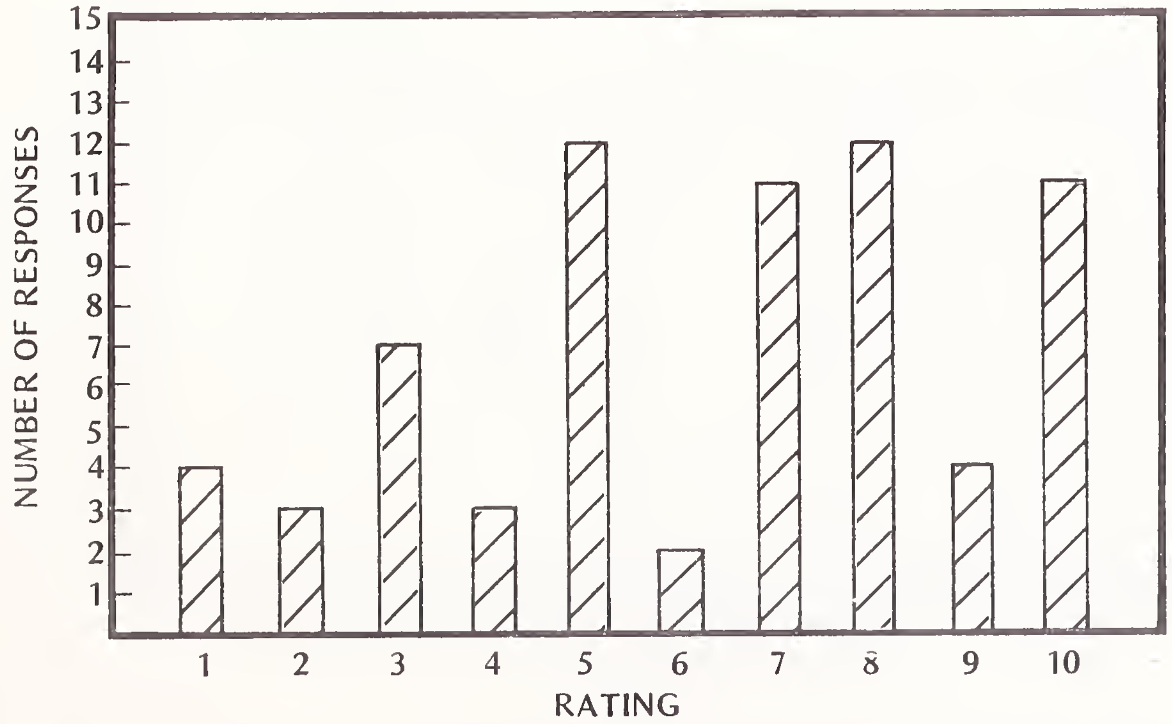
*EXHIBIT III-13 – Detail

EXHIBIT A-14*

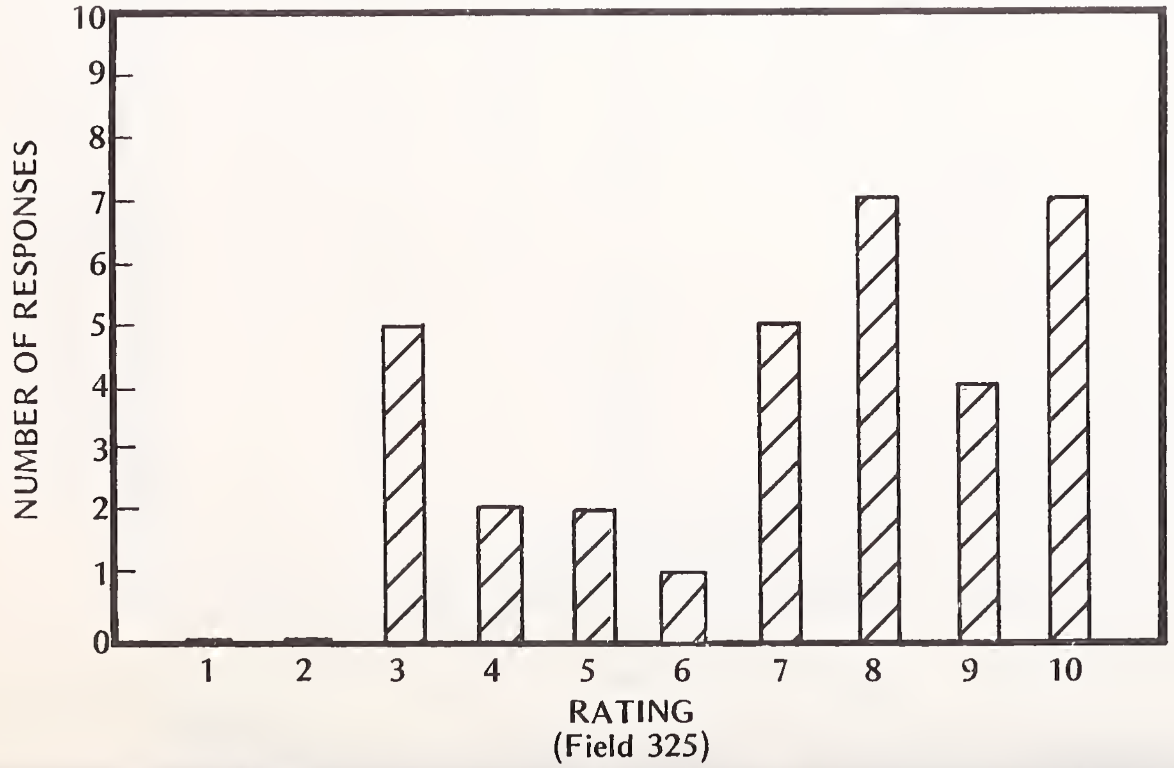
USER RATINGS - CAD/CAM INTEGRATION OBSTACLES

LACK OF STANDARDS

MECHANICAL APPLICATIONS
MEAN = 6.3

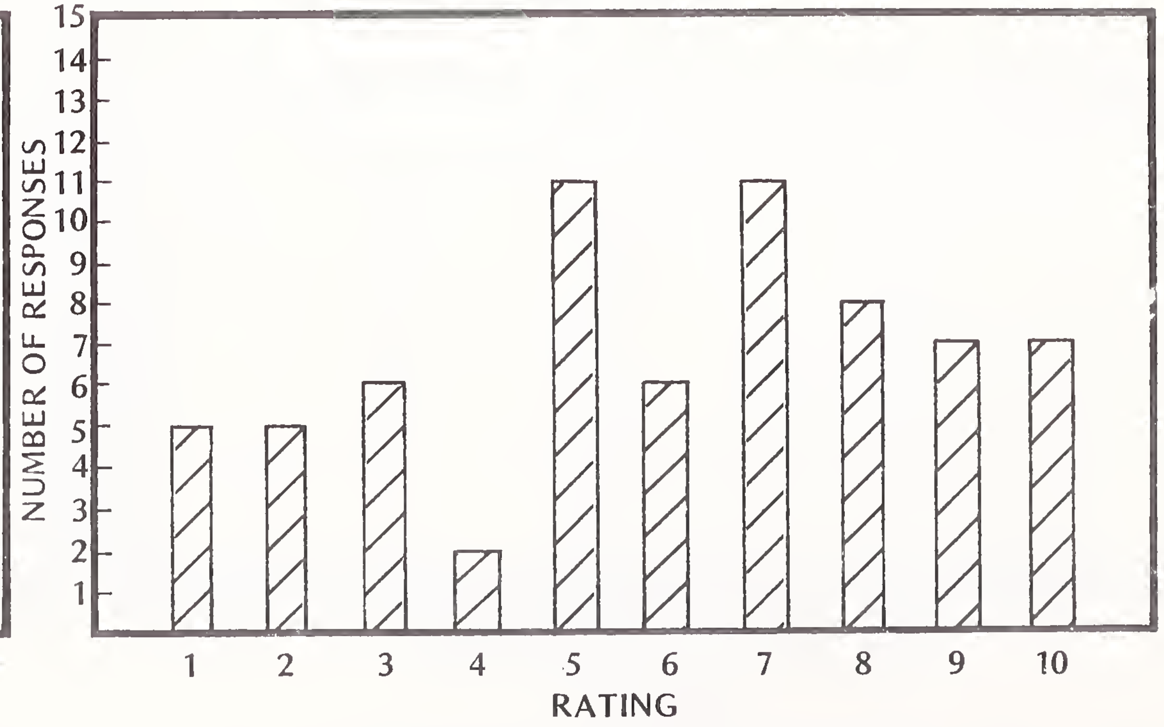


ARCHITECTURAL APPLICATIONS
MEAN = 7.2

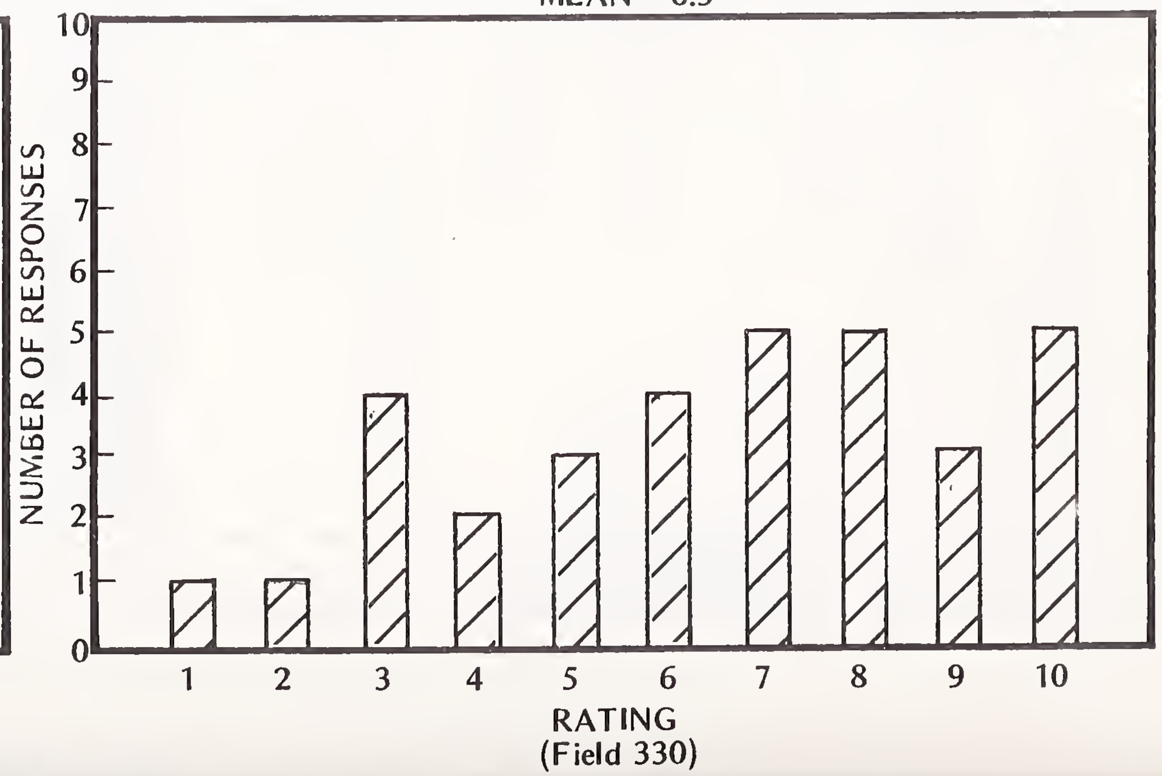


ORGANIZATIONAL CONFLICTS

MECHANICAL APPLICATIONS
MEAN = 6.0



ARCHITECTURAL APPLICATIONS
MEAN = 6.5



1 = NO OBSTACLE, 10 = GREAT OBSTACLE

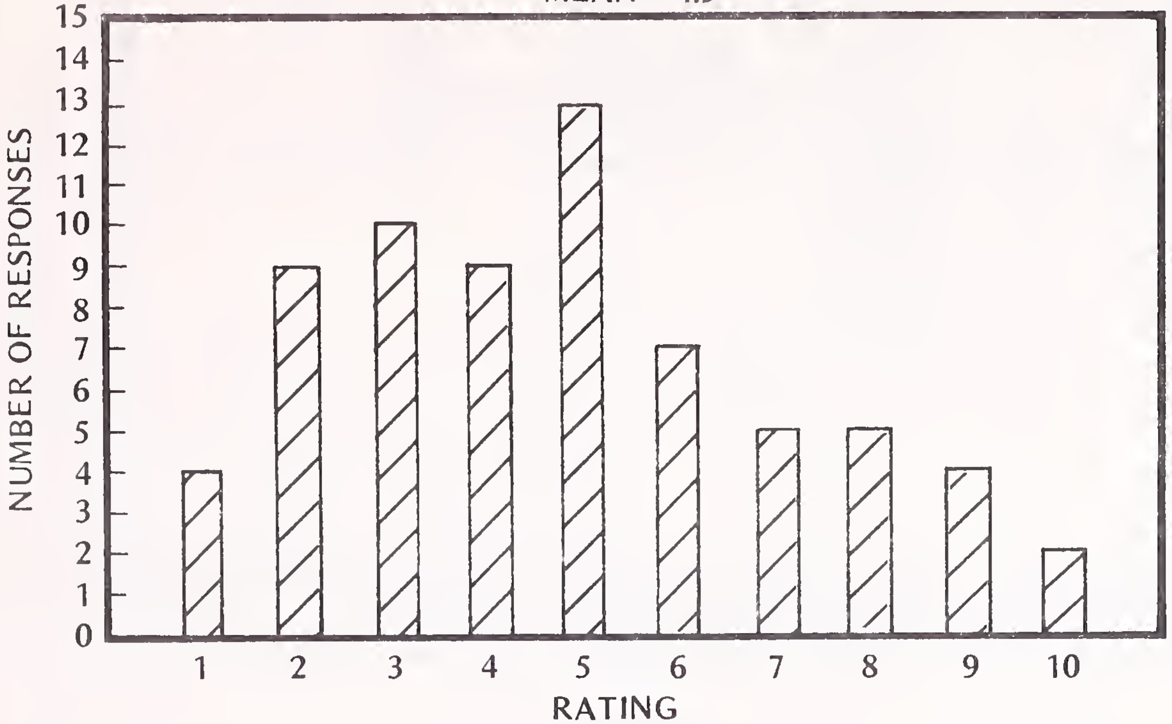
*EXHIBIT III-14 — Detail

EXHIBIT A-15

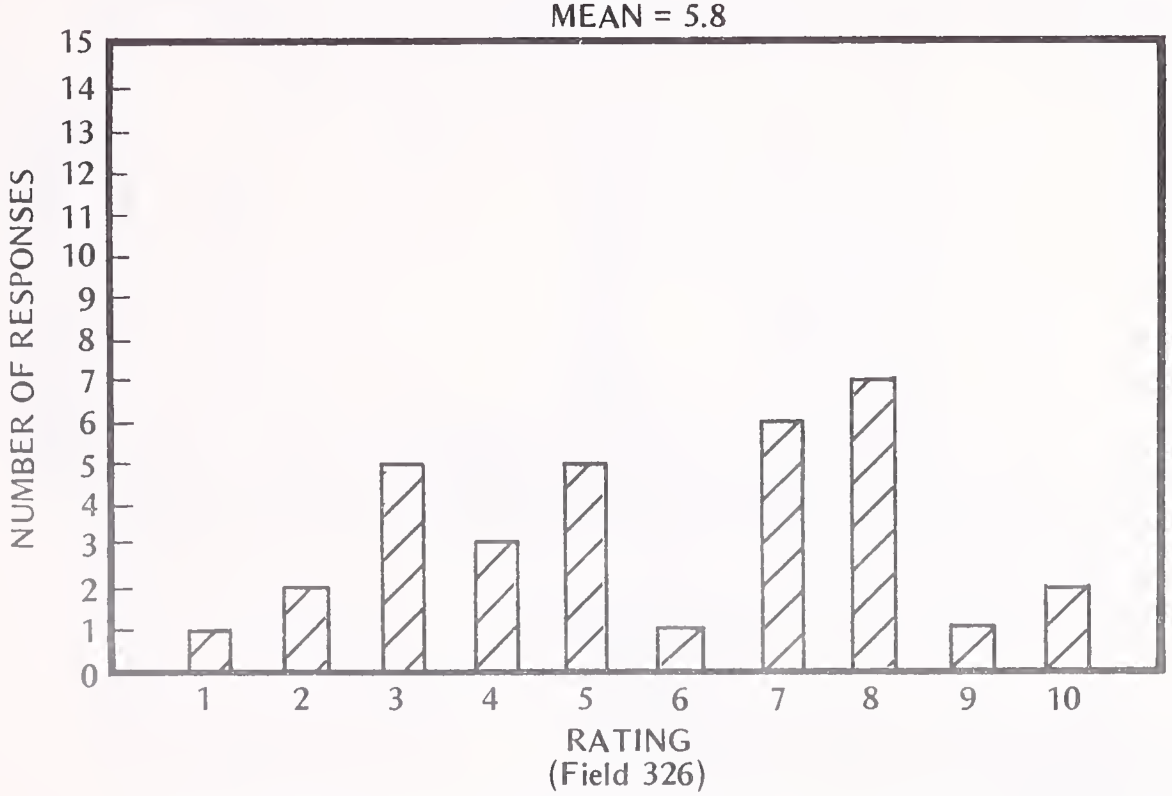
USER RATINGS - CAD/CAM INTEGRATION OBSTACLES

COMPLEXITY

MECHANICAL APPLICATIONS
MEAN = 4.9

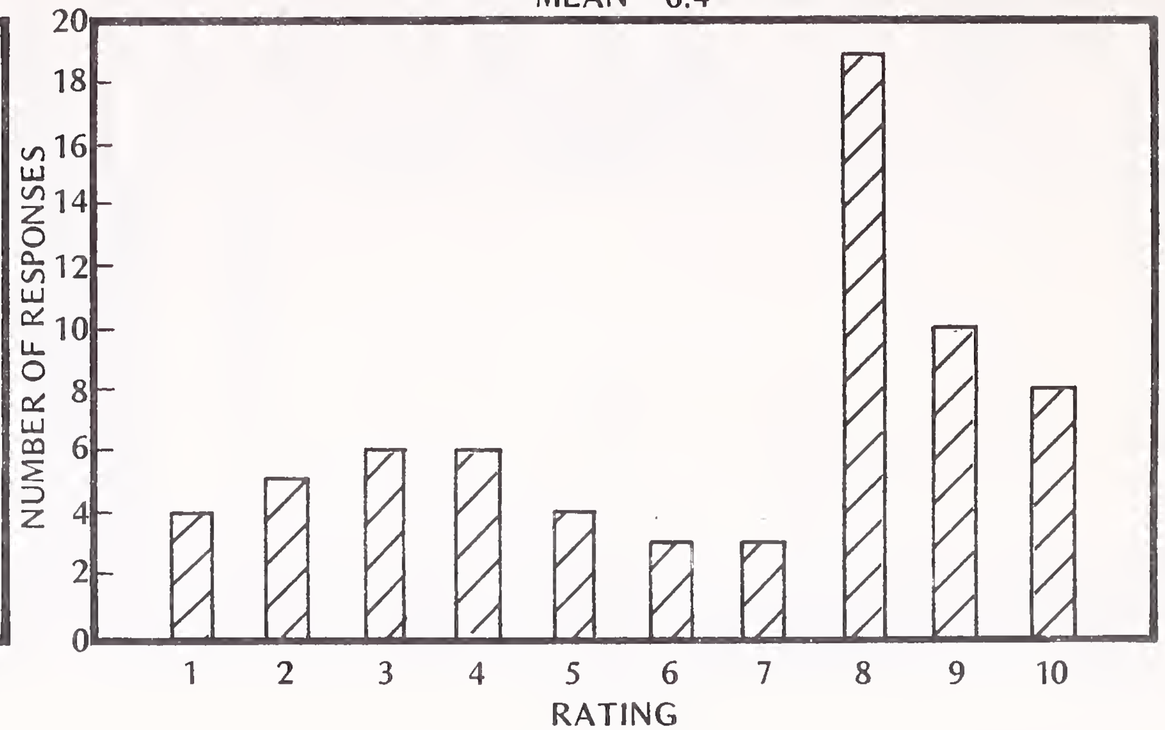


ARCHITECTURAL APPLICATIONS
MEAN = 5.8

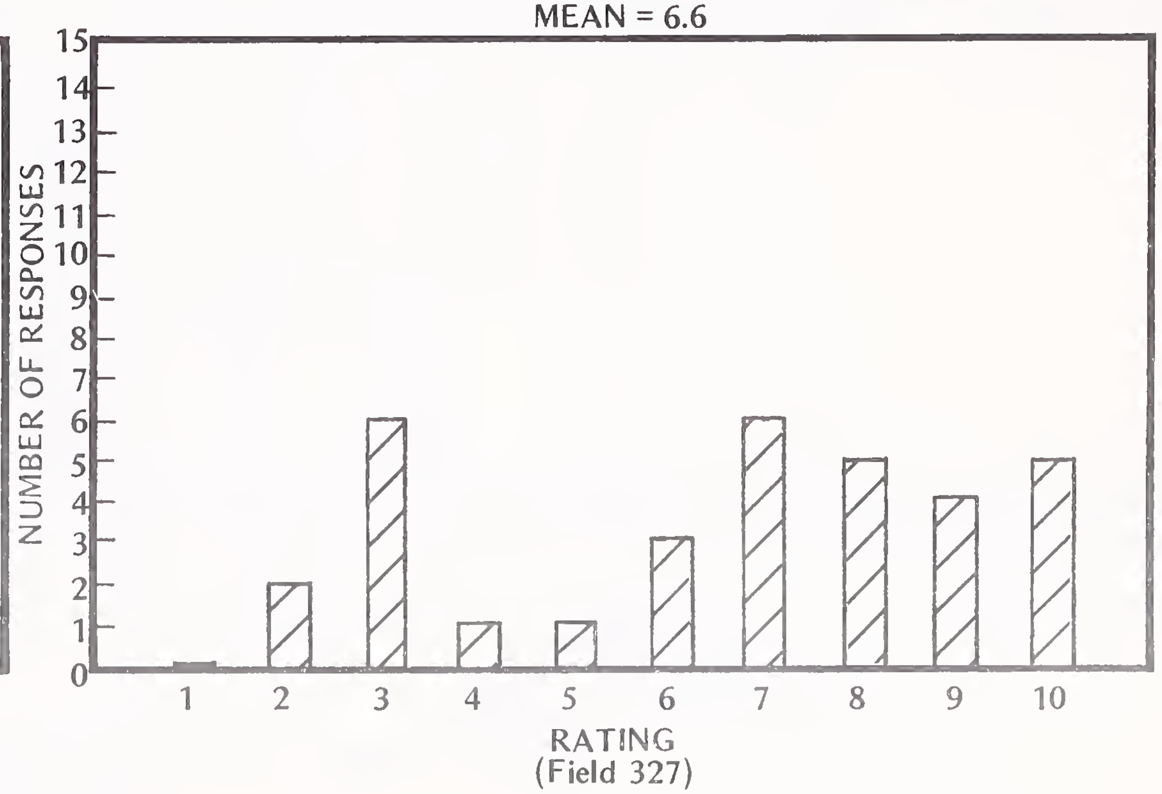


INCOMPATIBLE SYSTEM COMPONENTS

MECHANICAL APPLICATIONS
MEAN = 6.4



ARCHITECTURAL APPLICATIONS
MEAN = 6.6



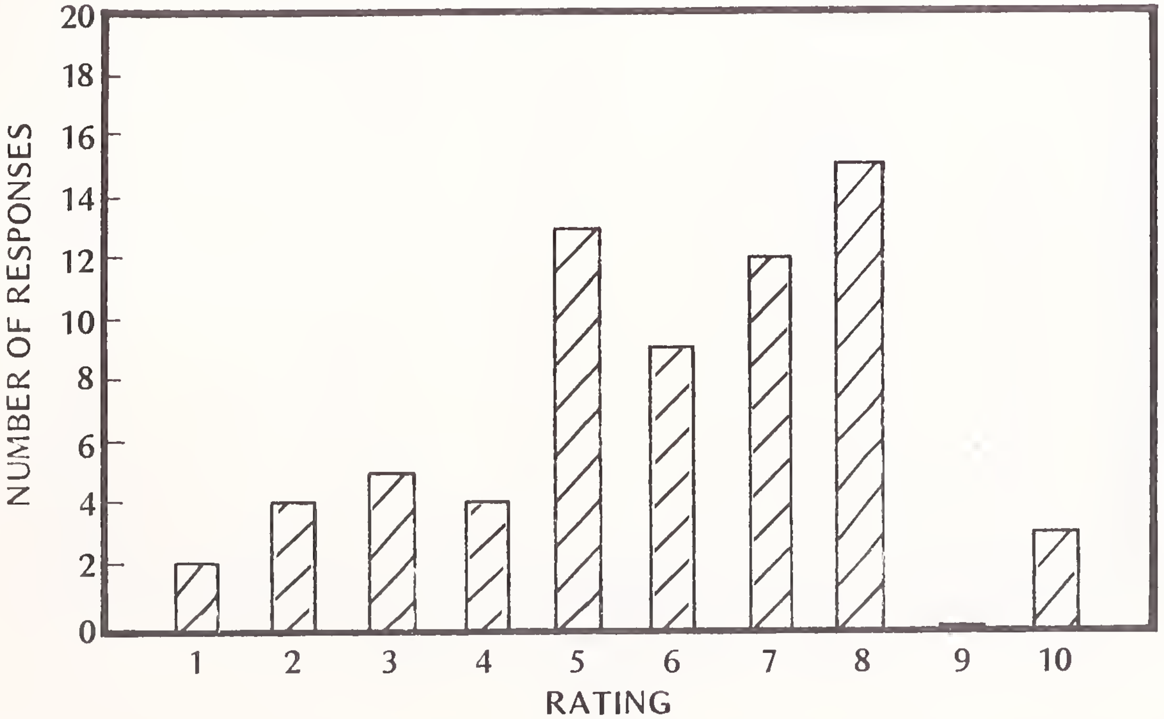
1 = NO OBSTACLE, 10 = GREAT OBSTACLE   *EXHIBIT III-15 — Detail

EXHIBIT A-16*

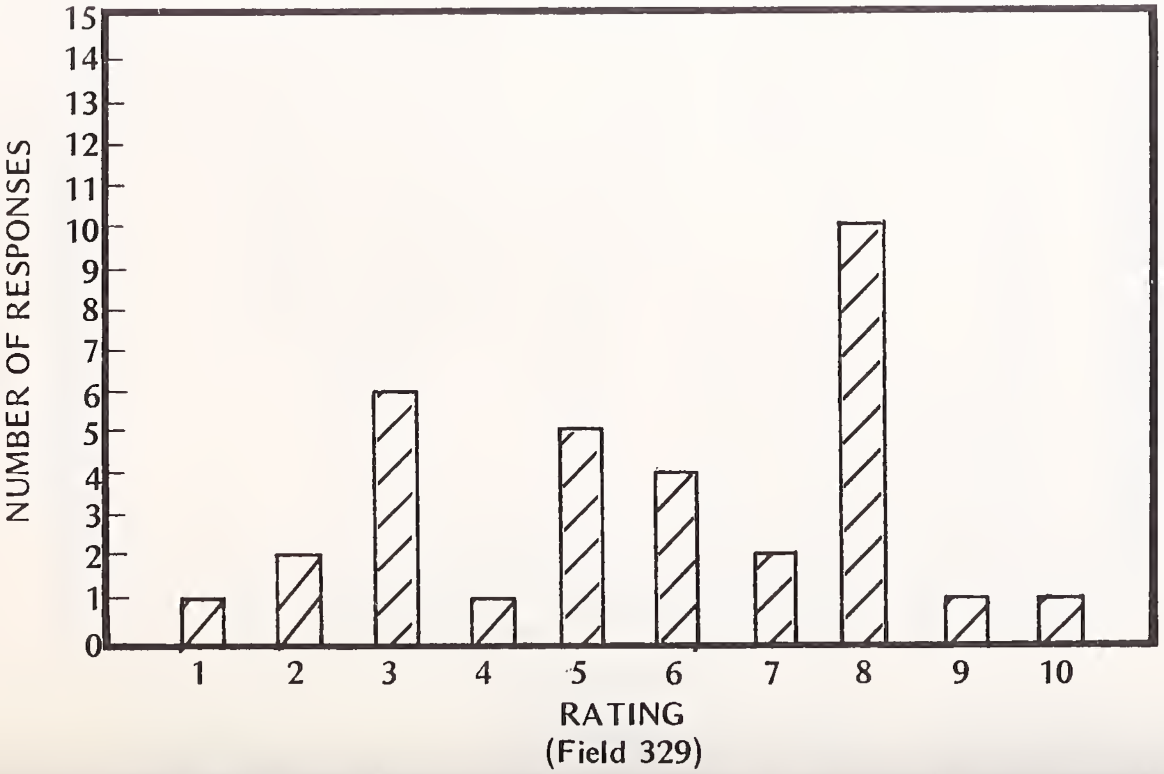
USER RATINGS - CAD/CAM INTEGRATION OBSTACLES

COST

MECHANICAL APPLICATIONS
MEAN = 5.9

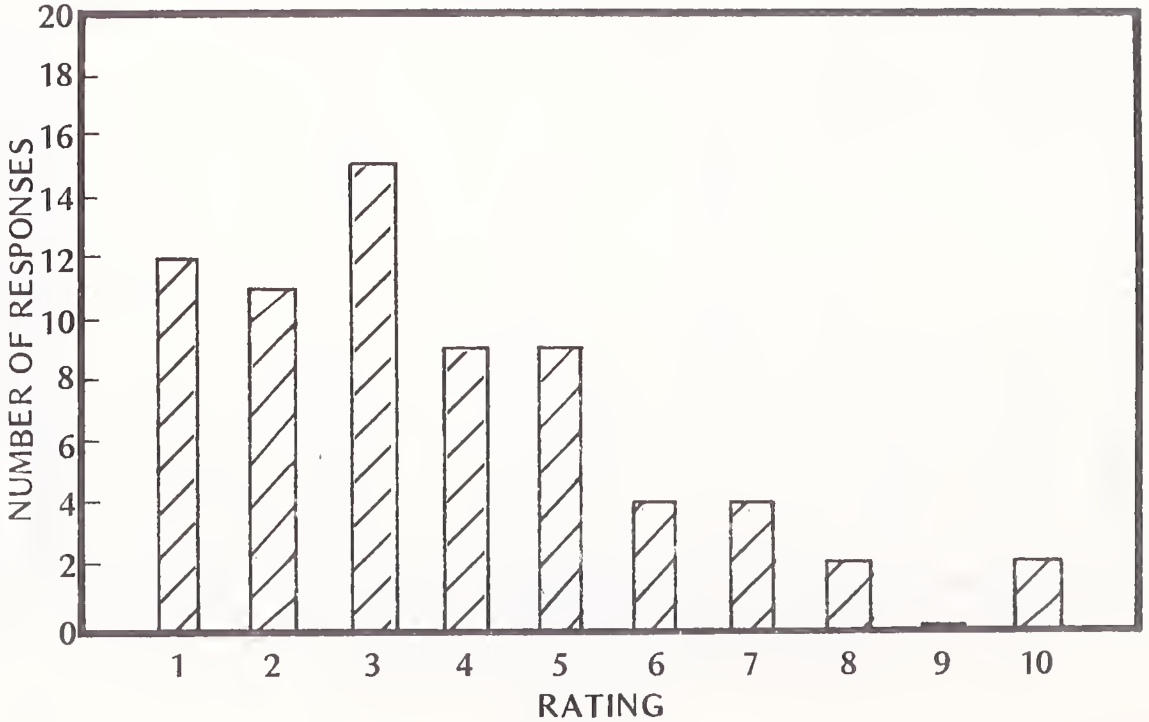


ARCHITECTURAL APPLICATIONS
MEAN = 5.7

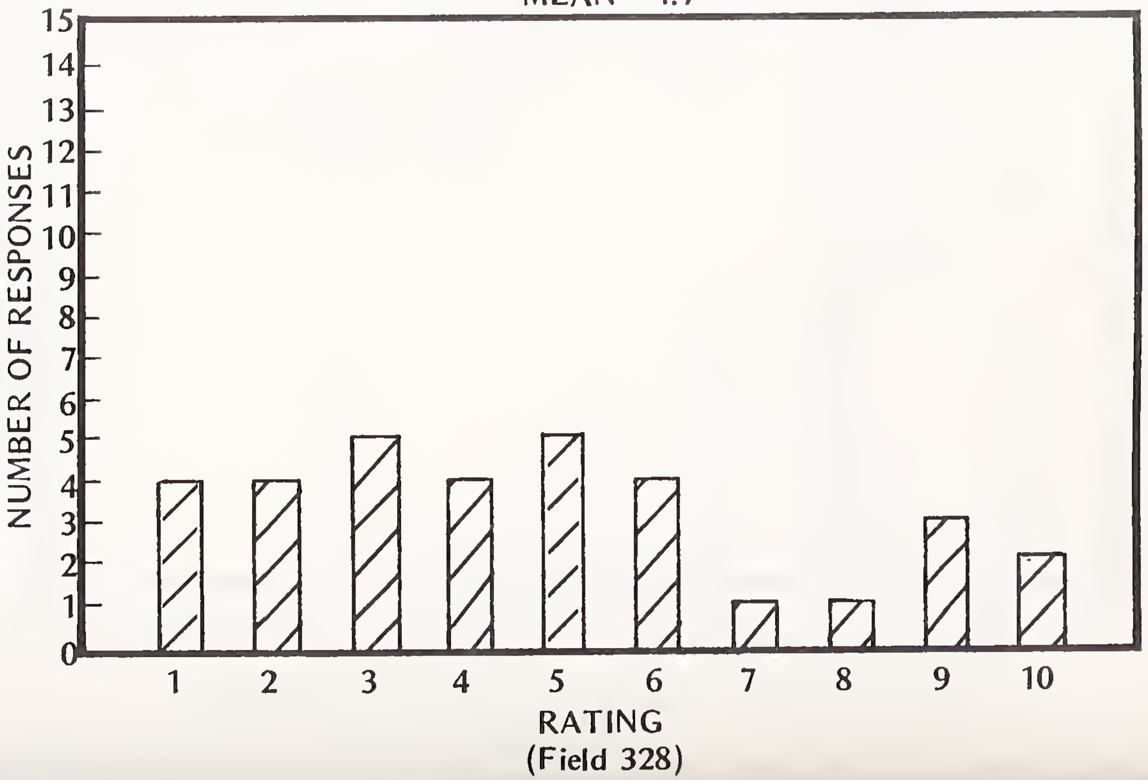


DATA SECURITY

MECHANICAL APPLICATIONS
MEAN = 3.6



ARCHITECTURAL APPLICATIONS
MEAN = 4.7

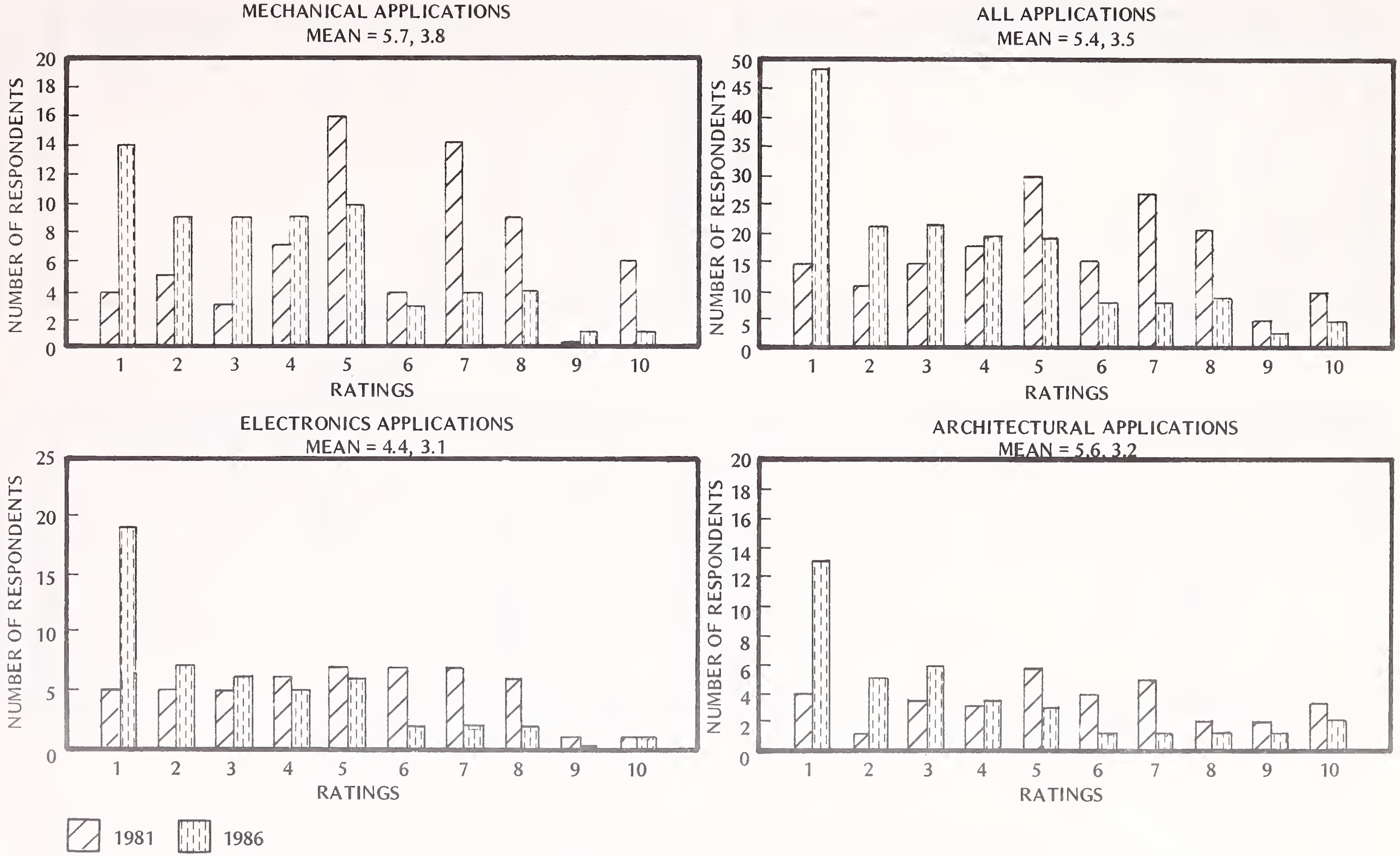


1 = NO OBSTACLE, 10 = GREAT OBSTACLE

*EXHIBIT III-16 — Detail

EXHIBIT A-17*

USER RATINGS - ADEQUACY OF STORAGE TUBE DISPLAYS

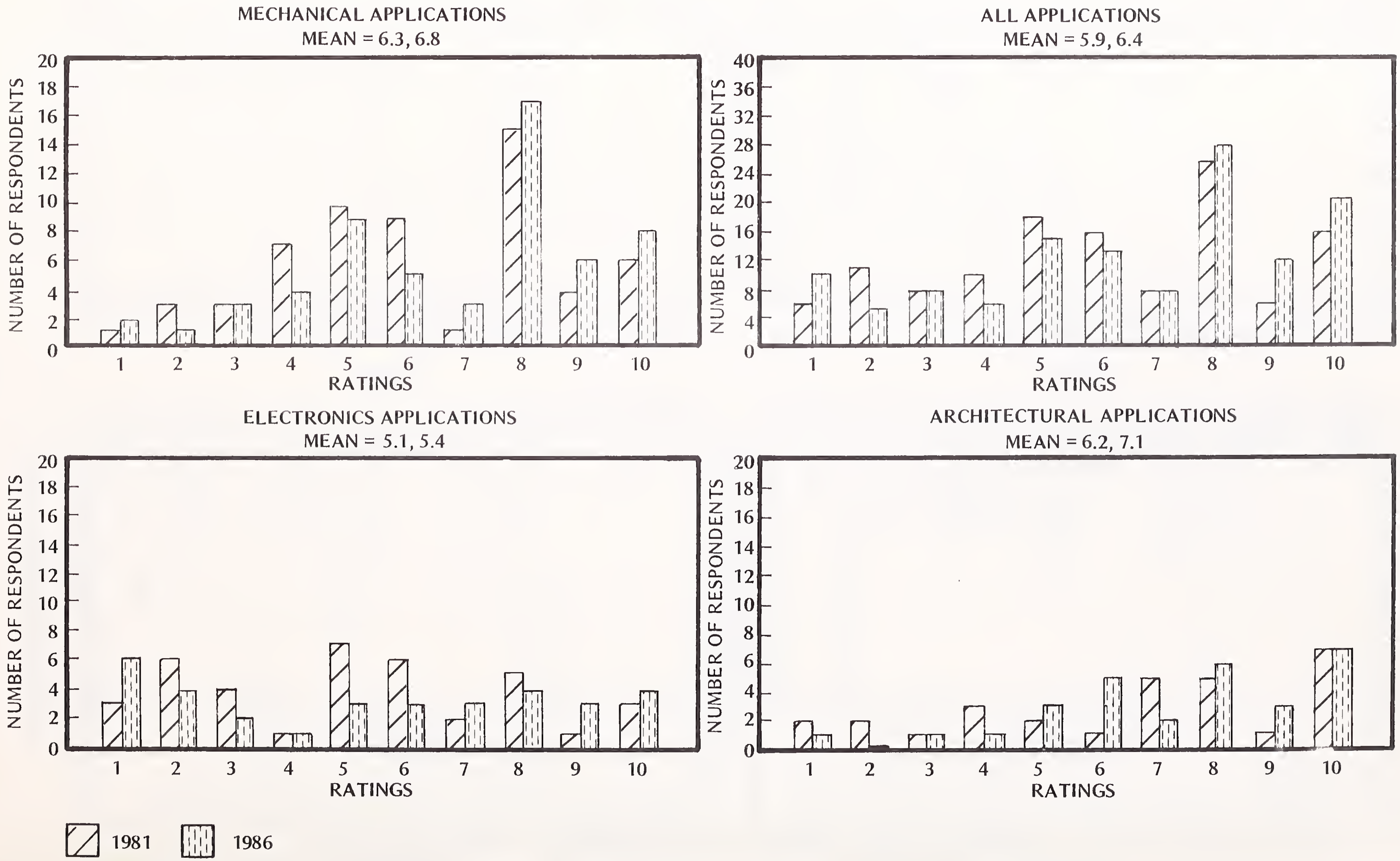


(Field 190) (Field 191)
1 = INADEQUATE, 10 = EXCEEDS NEEDS

*EXHIBIT III-17 – Detail

EXHIBIT A-18*

USER RATINGS - ADEQUACY OF STROKE REFRESH DISPLAYS

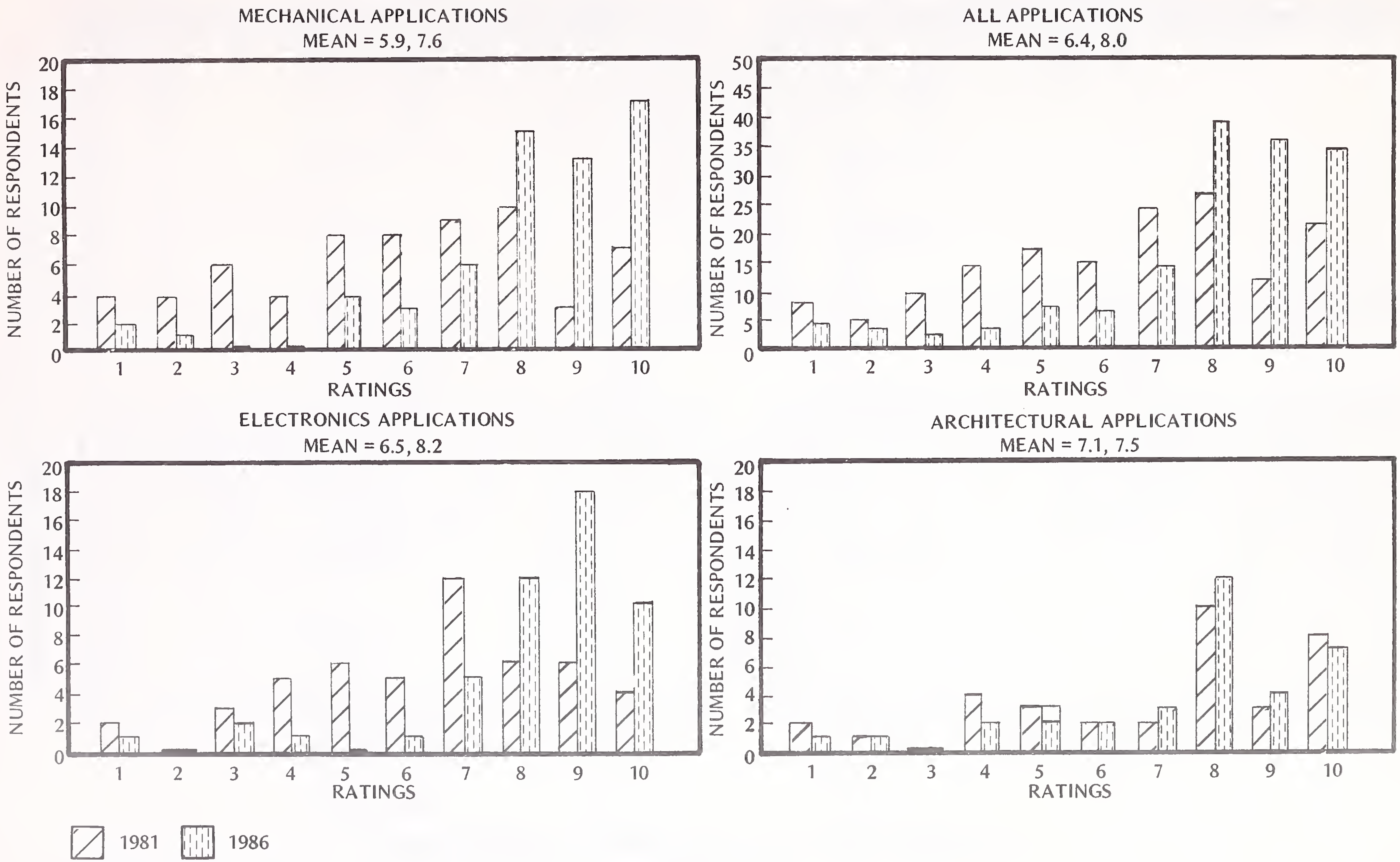


(FIELD 192) (FIELD 193)
1 = INADEQUATE, 10 = EXCEEDS NEEDS

*EXHIBIT III-18 – Detail

EXHIBIT A-19*

USER RATINGS - ADEQUACY OF RASTER SCAN DISPLAYS

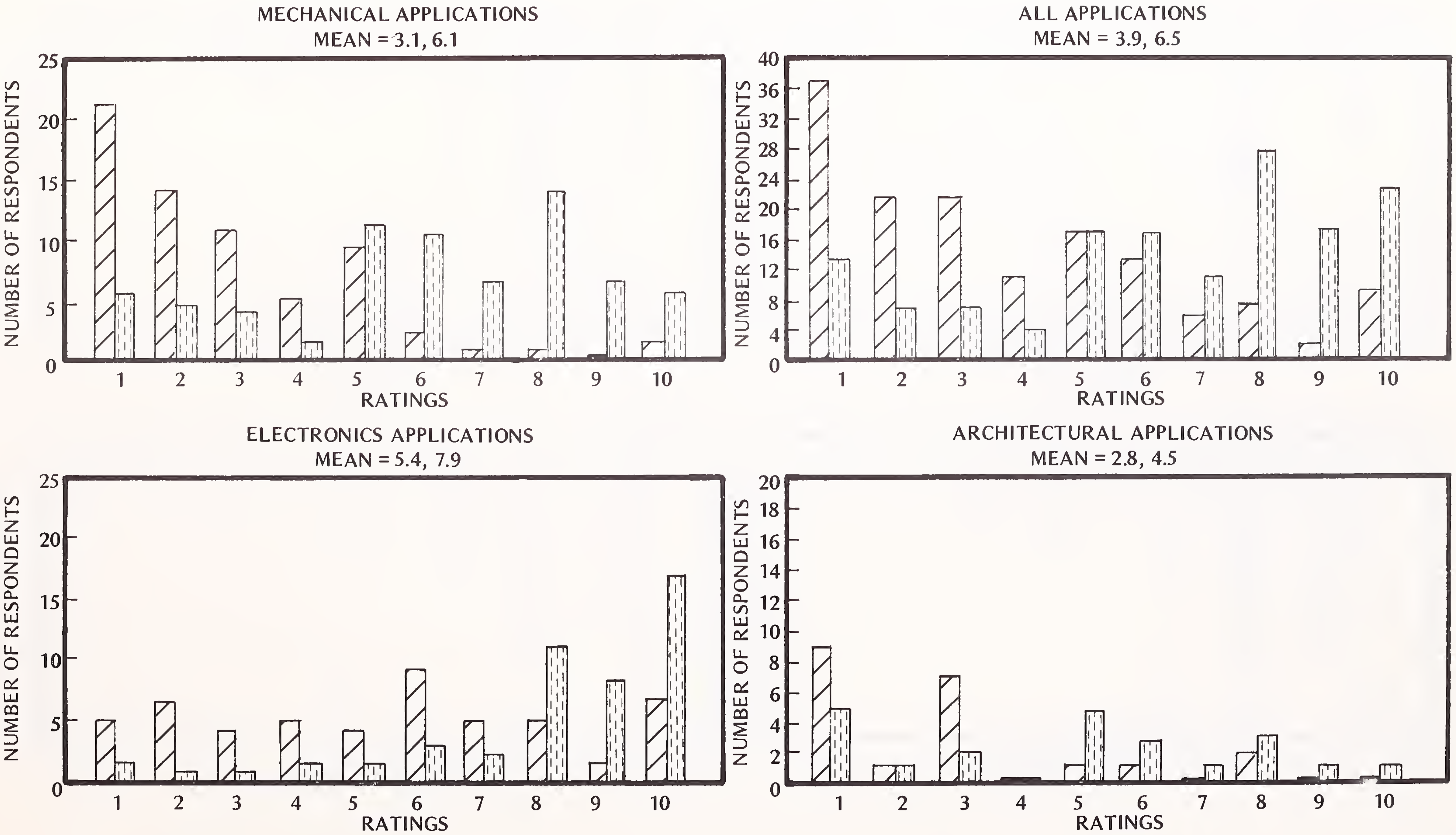


(FIELD 194) (FIELD 195)
1 = INADEQUATE, 10 = EXCEEDS NEEDS

*EXHIBIT III-19 – Detail

EXHIBIT A-20*

USER RATINGS - IMPORTANCE OF COLOR DISPLAYS



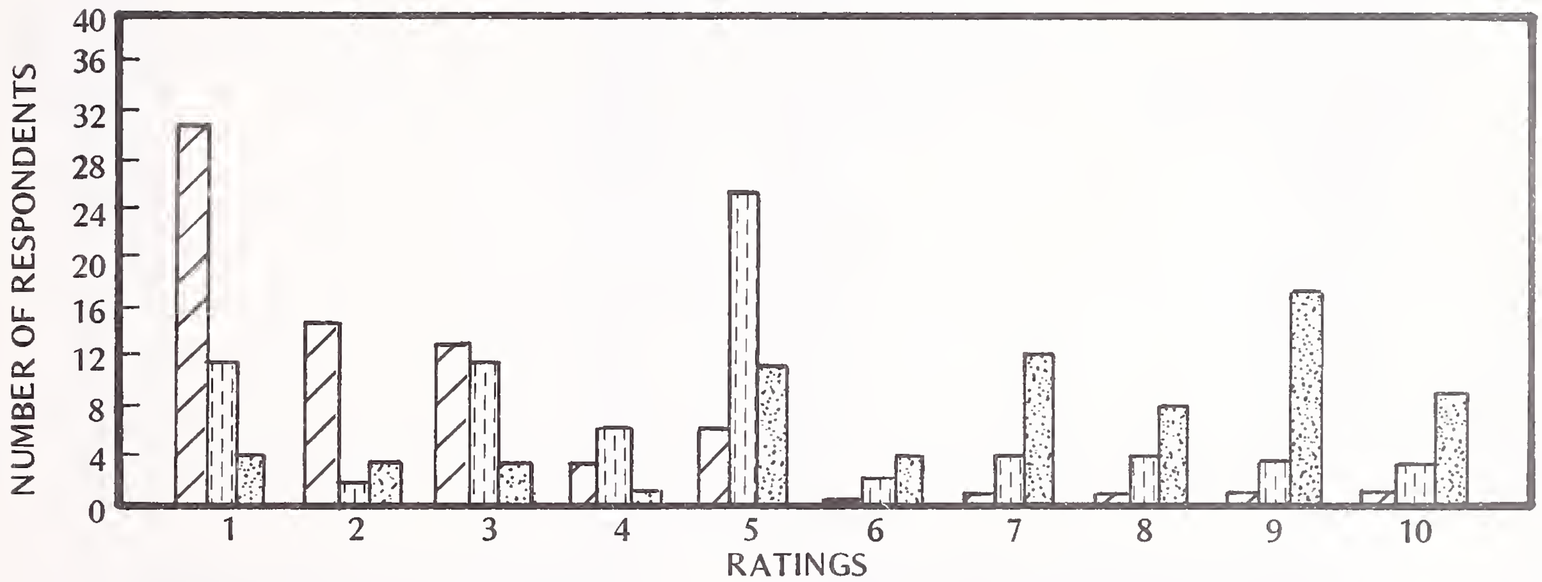
1981 1986
(Field 206) (Field 207)
1 = NO REQUIREMENT, 10 = ABSOLUTELY ESSENTIAL

*EXHIBIT III-20 – Detail

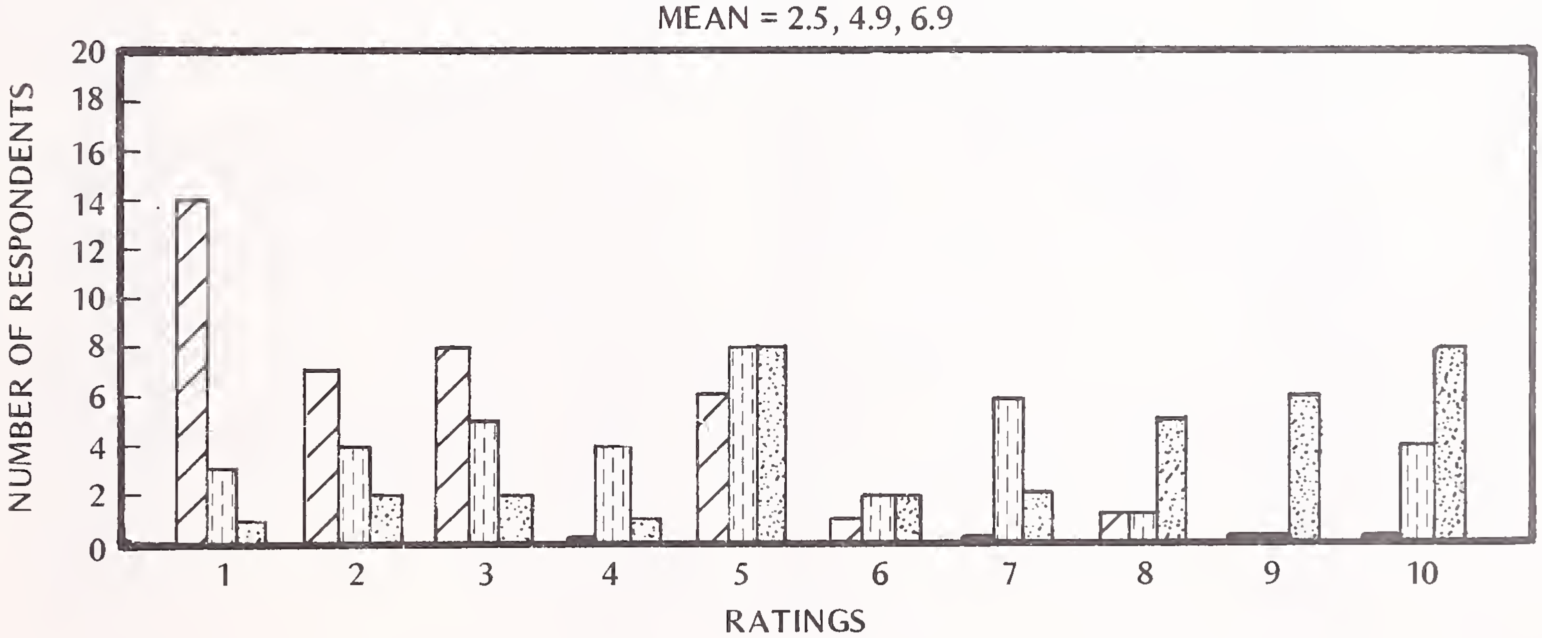
EXHIBIT A-21*

LIKELIHOOD OF CONVENTIONAL
DRAWING MEDIA OBSOLESCENCE

MECHANICAL APPLICATIONS
MEAN = 2.4, 4.6, 6.9



ARCHITECTURAL APPLICATIONS
MEAN = 2.5, 4.9, 6.9



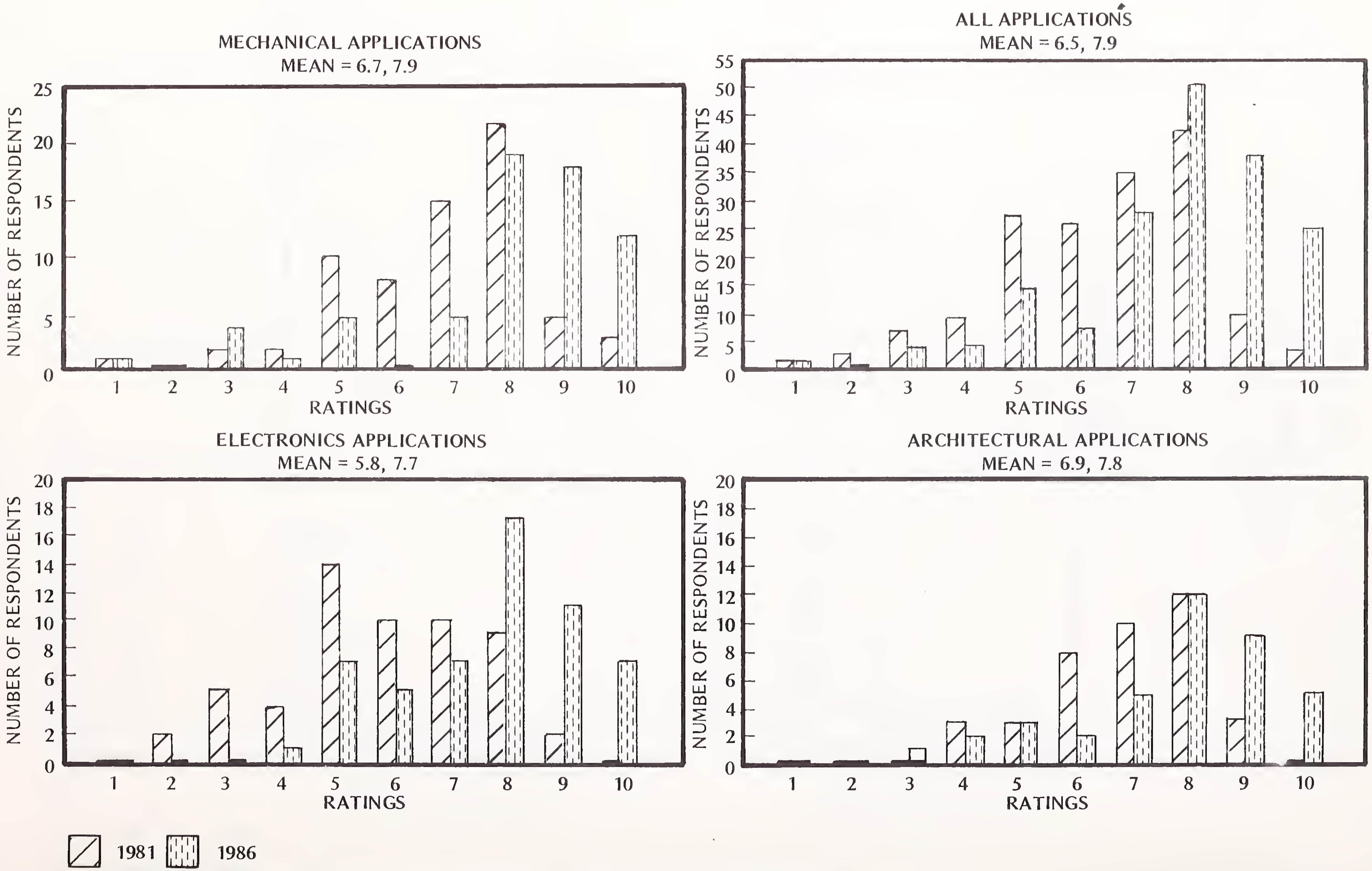
1983 1986 1990

(Field 242) (Field 243) (Field 244)
1 = IMPOSSIBLE, 5 = 50/50 CHANCE, 10 = 100%

*EXHIBIT III-21 – Detail

EXHIBIT A-22*

USER RATINGS - SOFTWARE ADEQUACY



(Field 299) (Field 300)
1 = VERY POOR, 10 = EXCELLENT *EXHIBIT III-23 – Detail

EXHIBIT A-23*

USER RATINGS - QUALITY OF MAINTENANCE

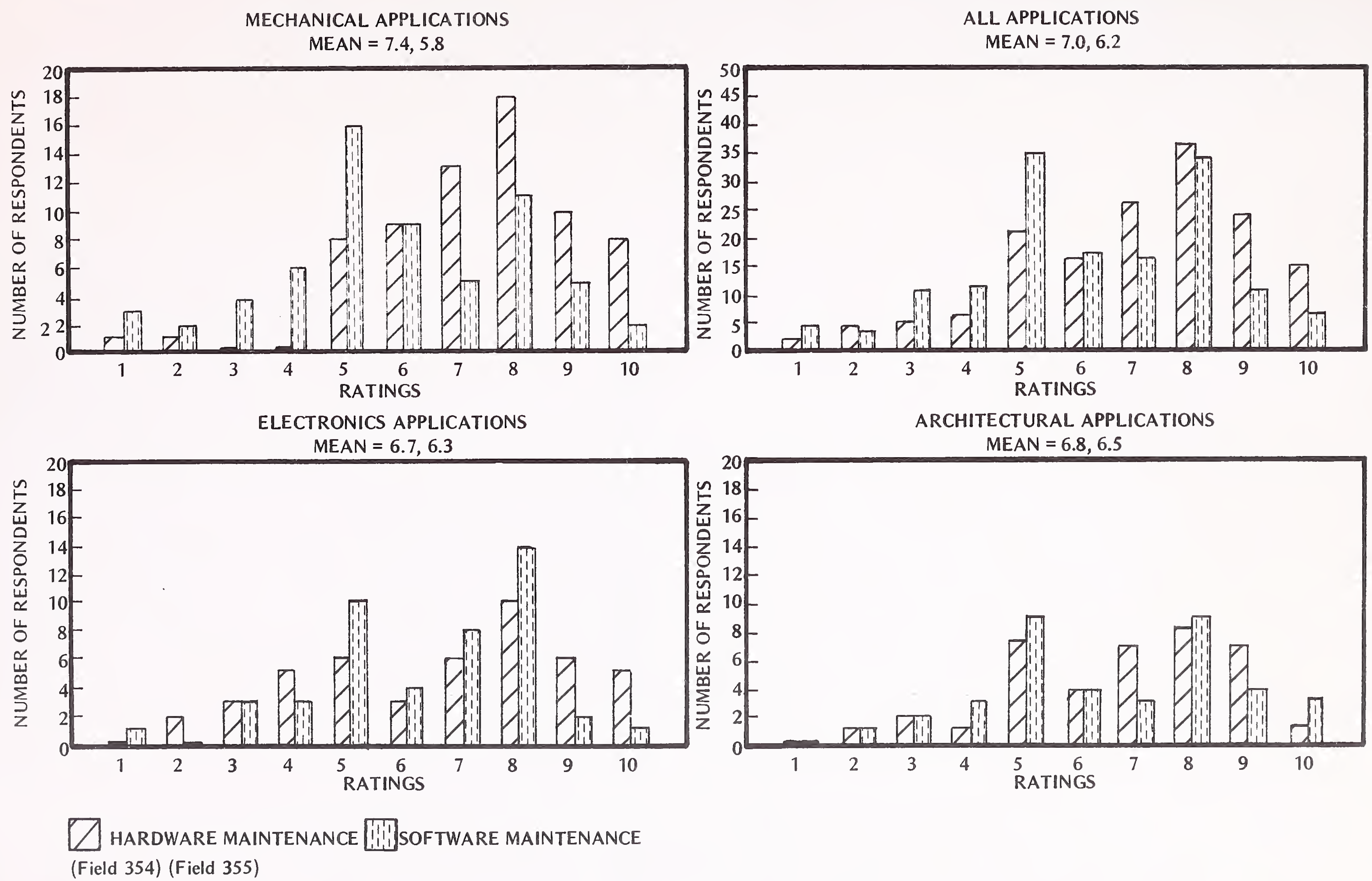


*EXHIBIT III-25 – Detail

APPENDIX B: GLOSSARY OF TERMS

APPENDIX B: GLOSSARY OF TERMS

AEROSPACE (product category). The subgroup of mechanical CAD/CAM users producing aerospace products such as airplanes, missiles, and aircraft engines.

ARTICULATION. Analysis of the movement of connected parts in complex assemblies.

BILL OF MATERIAL (BOM). A listing of all subassemblies, parts, and materials that go into an assembled part showing the quantities of each.

CAD (Computer-Aided Design). Application of computer and graphic technology to engineering, design, and drafting.

CAD/CAM. The integrated application of CAD and CAM.

CALLIGRAPHIC DISPLAY. A cathode ray tube display which writes each vector and character in the sequence of its commands. This display type provides high quality and good dynamics.

CAM. Application of computer and graphic technology to manufacturing engineering, planning, and control.

Computer Output Microfilm (COM). The technology for accepting digital data and recording it on microfilm at high reduction ratios and very high speeds. Useful for recording drawings as well as data.

CORE (SIGGRAPH). A proposed standard for software driving graphic devices, established by SIGGRAPH.

DATA BASE. A set of data records and files structured for a particular operating environment.

DATA BASE MANAGEMENT SYSTEM (DBMS). A software system that allows a user to structure a data base by defining the data, its organization, and the association between data elements. It also includes a data manipulation language (for access, sorting, merging, etc.) and controls for concurrent use (security, request, queueing, etc.). Functions as a common interface to multiple applications.

DATA TABLET. A device consisting of a pad and stylus used to input commands, designate elements, or to digitize drawings for a CAD system.

DISCRETE (product cateogry). The subgroup of mechanical CAD/CAM users producing discrete products such as conveyors, hand tools, electric motors, and air filters.

DISPLAY. A simple graphics terminal or the graphics display component of a more complex terminal.

DISTRIBUTED DATA BASE. A data base which is physically located at multiple sites, with each site having a part of the total data base. The sites are usually linked to a central site as well as having access to each other.

DISTRIBUTED PROCESSING. Multiple computers simultaneously processing elements of a CAD or CAM task.

DYNAMIC MOTION (display). A capability of a display to rapidly and continuously change the viewpoint under operator command.

ENGINEERING/MANUFACTURING DATA BASE. A combined CAD/CAM data base used by both engineering and manufacturing.

FAMILY OF PARTS. A process for defining generic part attributes which, when combined with user-specified parameters, will perform automatic CAD or CAM operations such as drawing, NC programming, or testing and simulation.

FINITE ELEMENT ANALYSIS. As used in this report, this includes all tasks involved in structural analysis using finite element methods: preprocessing or mesh generation, finite element analysis processing, and post-processing.

GKS (Graphic Kernel System). A proposed European standard for interchange of data between CAD systems.

GROUP TECHNOLOGY. The application of classification and coding technology to search a data base for information on similar parts and to apply this to CAD and CAM tasks.

ICAM. U.S. Air Force Integrated Computer Aided Manufacturing program for manufacturing technology.

IGES (Initial Graphics Exchange Specification). A proposed standard for the interchange of data between CAD systems. Developed by the National Bureau of Standards under contract from the ICAM program.

INTELLIGENT WORKSTATION. A CAD or CAM workstation which performs many tasks internally and independent of the host computer.

IPAD (Integrated Programs for Aerospace Vehicle Design). A NASA program to develop an integrated CAD/CAM system for aerospace applications.

KINEMATICS. Analysis of articulated assemblies.

KINETICS. Analysis of dynamic loads.

LAYERING. A technique to assign geometric and other data to spatially related layers, which can be viewed or plotted independently.

LIGHT PEN. A device used to input commands and to designate elements by pointing at or touching the display.

MANAGEMENT INFORMATION SYSTEM (MIS). A data processing system specifically designed to provide business managers with company, financial, project, or program data.

MASS PROPERTIES. Calculation of weights, centers of gravity, and moments of inertia for a closed volume.

MOBILE/TRANSPORTATION (product category). The subgroup of mechanical CAD/CAM users producing products for transportation or similar products, such as automobiles, tractors, and construction machines.

NUMERICAL CONTROL (NC). CAM technology and systems for programming and controlling numerically controlled machines.

NCGA. National Computer Graphics Association.

NC POST PROCESSORS. Computer programs to adopt generic NC commands to drive specific NC machines.

NESTING. Software to automatically or interactively arrange patterns for parts within stock material boundaries.

NETWORKING. The interconnection and control of remotely located systems and devices over communications lines.

RASTER DISPLAY. A CAD display using television technology. Currently has less resolution than Calligraphic, better dynamics than memory tubes, and lower cost.

SHOP FLOOR CONTROL. Control of the progress of each customer order or stock order through the successive operations of its production cycle and the collection of data regarding actual completion results or status.

SIGGRAPH. Special Interest Group on Graphics, an organization within ACM (Association for Computing Machinery).

SOLID MODEL. A computer based representation of a complete, enclosed object or part; the same as a volumetric model.

STORAGE TUBES. A graphics display in which the image is stored on an element behind the viewing screen. Graphics elements can be added to the stored image, but the entire screen must be erased and repainted if elements are deleted. Since this image is not refreshed as in raster or stroke tubes, there is no flicker; however, repaint time for large amounts of data can be significant compared to other technologies.

STROKE REFRESH. A calligraphic display.

SURFACE MODEL. A computer based representation of a surface patch. The surface may be of many types, including ruled, tabulated cylinders, and sculptured.

TRIMMING. The operation of removing the parts of a geometric model which extend past a designated boundary.

TRUE 3-D GEOMETRY. A geometry model for a part which can be viewed from any direction with automatic generation of correct perspective or orthographic views.

TURNKEY CAD. A complete packaged CAD system including all software, computer and other hardware, and user support and training.

VECTOR STROKE. A calligraphic display.

VOLUMETRIC MODEL. The same as a solid model.

WIRE FRAME. A 3-D representation of edges made up of line segments.

APPENDIX C: RESPONDENT PROFILE

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- The following lists of respondent titles and company names are provided to give an indication of the extent of the study and level of people interviewed.

- Individual names are not listed to maintain the confidentiality of the respondents.

- Only those companies who gave their permission for disclosure are listed. European companies are marked with an asterisk. All Japanese interviews were marked confidential.

- A number of interviews were conducted with two or more people. Most nonmanagerial respondents were interviewed in conjunction with a manager. Titles were not recorded for all people interviewed.

- Numbers in parentheses after some titles indicate the number of respondents with that title.

A. USER RESPONDENT TITLES

- Nonmanagerial/Technical.

  - Assistant Professor (2).
  - CAD Specialist (5).
  - Computer Drafting Engineer.

- Computing Services Engineer.
- Design Draftsman.
- Design Engineer (3).
- Engineering Analyst.
- Fellow Engineer.
- Layout Draftsman.
- Manufacturing Engineer (2).
- Office Engineer.
- Physical Engineer.
- Principal Engineer.
- Senior Computer Graphics Development Engineer.
- Senior Design Engineer (2).
- Senior Engineer.
- Senior LSI Designer.
- Senior Member, Technical Staff.
- Senior Principal Engineer.
- Senior Staff Consultant.
- Senior Structural Engineer.
- Software Engineer.
- Systems Analyst (2).

• Supervisory/Managerial.

  - Applications Manager.
  - Automated or Computer Graphics Manager (6).
  - Branch Chief.
  - CAD/CAM Group Leader or Supervisor (11).
  - CAD/CAM Manager (21).
  - CAM Software Engineering Manager.
  - Chief Structural Engineer.
  - Circuit Design Department Manager.
  - Computer Documentation Manager.
  - Computer Graphics Manager.
  - Computer Graphics Supervisor (4).
  - Control Systems Design Manager.
  - Corporate Design Aids Manager.
  - Data Processing Manager (2).
  - Department Manager (2).
  - Design Automation Manager (2).
  - Design Engineering Group Manager.
  - Design Engineering Manager.
  - Design Graphics Manager.
  - Design Manager.
  - Drafting Manager (2).
  - Drafting Services Manager.
  - Drafting Supervisor (2).
  - Electrical Design Supervisor.
  - Engineer In Charge.
  - Engineering and Scientific Systems Manager (3).
  - Engineering Services Manager (3).

- Engineering Supervisor.
- Engineering Support Manager.
- Engineering and Technical Support Manager.
- General Supervisor.
- Interactive Graphics Manager.
- Lead Designer.
- Management Information Systems Manager.
- Manufacturing Project Engineer.
- Mechanical Design and Drafting Supervisor (3).
- Operations Manager (5).
- Operations Supervisor.
- Product Manager.
- Production Automation Head.
- Program Director.
- Program Manager.
- Project Engineer.
- Project Manager.
- Research and Development Manager (3).
- Scientific Computing Manager.
- Section Chief/Section Manager (3).
- Senior Project Engineer.
- Software Development Supervisor.
- Software Manager.
- Strategic Planning Manager.
- Systems and Development Supervisor (2).
- Systems Head.
- Systems Manager (3).
- Technical Computing Manager.
- Technical Section Supervisor.
- Unit Leader.

• Senior/Corporate Management.

  - Assistant Director.
  - Associate Division Head.
  - Chief Design Engineer.
  - Chief Designer.
  - Chief Engineer (2).
  - Director, Advanced Systems.
  - Director, Computer Services (3).
  - Director, Engineering Planning.
  - Director, Engineering and Research.
  - Director, Graphics Services.
  - Director, Purchasing.
  - Division Manager.
  - Division Manager, Technical Systems Development.
  - General Manager.
  - President (2).
  - Vice President, Operations.

B. USER RESPONDENT COMPANIES

- Mechanical Applications.

  - Advanced Computer Graphics.
  - Allen-Bradley.
  - Allis-Chalmers.
  - Alvey.
  - Austin Motors (Leyland).*
  - Avions Marcel Dassault.*
  - Baker Perkins.*
  - Barry-Wehmiller.
  - Beech Aircraft.
  - Bell Helicopter Textron.
  - Black and Decker.
  - BMW.*
  - Cable Belt.*
  - CAD/CAM Inc.*
  - California Polytechnic University.
  - Chevrolet Motor Division, General Motors.
  - Clark Equipment.
  - Dennison.
  - Didde Graphic Systems.
  - Digitran.
  - Doehler-Jarvis.
  - Donaldson Corporation.
  - Dure and Company.
  - Eaton Corporation.
  - Envirotech Corporation.
  - Fisher Body Division, General Motors.
  - Ford Motor Co.
  - Fraunhofer Institute.*
  - Galigher Co.
  - Garrett AiResearch Manufacturing Company.
  - General Motors Technical Center.
  - General Tire & Rubber.
  - Grumman Aerospace.
  - Harnischfeger.
  - Hydramatic Division, General Motors.
  - Inductotherm.
  - Koltanbar Engineering.
  - Kroy Industries.
  - Leeds and Northrup.
  - Limitorque.
  - Lockheed Missiles & Space Company.
  - Lucas Logic Ltd.*
  - Mahle.*

- Marathon le Tourneau.
- McDonnell Douglas.
- McNally Pittsburg Manufacturing.
- Merlin Gerin.*
- Messerschmidt, Belkow, Bloom.*
- NETRPIC.*
- Opel.*
- Perkins Engine.*
- Piper Aircraft.
- Pontiac Motor Division, General Motors.
- PSA.*
- Reliance Electric.
- Rockwell International.
- Rolls Royce Ltd.*
- Schindler Haughton Elevator Company.
- Siemens Research Inc.*
- A.O. Smith.
- Strippit-Houdaille.
- TRW.
- Volkswagen.*
- Jervis B. Webb.
- Western Gear.
- Yuba Heat Transfer.

- Electronic Applications.

  - Allen Organ.
  - Amdahl.
  - Cherry Semiconductor.
  - CNET.*
  - Codex Corporation.
  - Crouzet.*
  - Data General.
  - Digitron.
  - E-Systems.
  - Fairchild Camera & Instrument.
  - Firestone Tire.
  - Ford Aerospace & Communications.
  - General Instrument Microelectronics.
  - General Railway Signal.
  - GTE Microcircuit.
  - Harris Corporation.
  - Hewlett Packard.
  - Hughes Aircraft.
  - Integrated Circuit Engineering Company.
  - Integrated Circuit Systems, Inc.
  - Intel.
  - Interstate Electronics Corporation.
  - Lear Siegler.
  - Leeds and Northrup.

- Memorex.
- MFDL GE Semiconductor.*
- Microtronics, Inc.
- Motorola.
- National Semiconductor.
- Naval Ocean Systems Center.
- Owens-Illinois.
- Philips.*
- (RTC) Radio Technique.*
- Sperry Univac.
- Sperry Univac Design Automation.
- Taylor Instruments.
- TRW.
- Union Pacific Railroad.
- Western Electric.
- Westinghouse Electric.
- Weyfringe.*
- Xerox Corporation.

• Architectural Applications.

- Arco Oil & Gas.
- Automated Graphics Systems.
- B.E.&K.
- Bendy Engineering.
- Burns and Roe.
- Cabinet Structure et.*
- Caudill, Rowlett & Scott.
- CH2M Hill.
- Combustion Engineering.
- Elstree Computing.*
- Fluor Engineers & Constructors.
- Frito-Lay.
- Giffels Associates.
- Herman Blum Consulting Engineers.
- Houston Lighting & Power.
- Marathon Marine Engineering.
- Owens-Corning.
- Rust Engineering.
- Simons Eastern.
- J.E. Sirrine Company.
- Stanley Consultants, Inc.
- Stearns-Rogers.
- United Conveyor Corporation.
- U.S. Steel.
- Wilson & Company.

C. VENDOR RESPONDENT TITLES

- Assistant to the President.
- Chairman.
- Department Head, Civil Engineering.
- Director.
- Director,
  - Commercial.
  - Electronic CAD/CAM Systems.
  - Marketing (2).
  - Mechanical CAD/CAM Systems.
  - Operations.
  - Technical.
- Executive Vice President, Marketing Manager,
  - Division.
  - Marketing (2).
  - Marketing Development.
  - National Sales.
  - Product Marketing (2).
  - Product Planning.
  - Systems Development.
- President (3).
- Vice President,
  - Marketing.
  - Program Product Development (2).

D. VENDOR RESPONDENT COMPANIES

- Applicon.
- Applied Research of Cambridge Ltd.*
- Automated Systems.
- Benson, Inc.
- Boeing Computer Services.
- California Computer Products.
- Calma.
- Cambridge Interactive Systems Ltd.*

- CISI.*
- Comarc Design Systems.
- Computervision.
- Comsat General Integrated Systems.
- Design Automation Systems.
- Digital Equipment Corporation.
- Engineering Systems Consultants.
- Evans & Sutherland.
- Ferranti Cetec Graphics Ltd.*
- Grafcon.
- Holguin Associates.
- Intergraph.
- Lockheed California Company.
- Manufacturing Data Systems.
- Matra Datavision.*
- Racal-Redac Marketing Ltd.*
- SERI Renault Ingeniene.*
- Sigma Design.
- Summagraphics Corporation.
- Vector General.